Professional Paper No. 12

Series { A, Economic Geology, 22
B, Descriptive Geology, 25

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

OF THE

GLOBE COPPER DISTRICT, ARIZONA

BY

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WASHINGTON

GOVERNMENT PRINTING OFFICE

1903

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ILLUSTRATIONS.

GEOLOGY OF THE GLOBE COPPER DISTRICT, ARIZONA.

By F. L. Ransome.

INTRODUCTION AND ACKNOWLEDGMENTS.

The investigation of the Globe district was begun early in the summer of 1901, a month being devoted to preliminary reconnaissances and areal mapping of the geology. Work was subsequently resumed in October of the same year, with the efficient assistance of Dr. John D. Irving, and continued to the 1st of February, 1902. Much time was necessarily consumed in studying and mapping the intricately faulted country in the northwest portion of the area, and when the season was perforce brought to a close, it was with the reluctant feeling that the detailed study of the faults of the northern half of the quadrangle still offered attractive byways of investigation leading beyond the bounds prescribed by economic conditions for the present study. It is hoped that at some future time geological work may be undertaken in adjacent quadrangles and a broader basis provided for a discussion of the structural features of this interesting region.

The preparation of this report has been facilitated by various courtesies rendered by the Old Dominion and United Globe companies through their local representatives, Mr. F. W. Hoar and Mr. N. S. Berray, who lent their cordial cooperation to the furtherance of the work. For various chemical analyses and tests I am indebted to Dr. W. F. Hillebrand and Dr. E. T. Allen, of the Chemical Division of this Survey, and for paleontological notes embodied in the following pages to Prof. H. S. Williams, of Yale, and Dr. Geo. H. Girty, of the Geological Survey.

From Mr. S. F. Emmons, geologist in charge of the investigation of metalliferous deposits, I have received such general oversight and criticism as gracefully turns the performance of his official duties into a source of personal regard and obligation.

GEOGRAPHY.

For the purposes of this report the Globe copper district may conveniently be considered as coextensive with the cartographic unit adopted by this survey,

FIG. 1.—Index map, showing position of the Globe quadrangle and the approximate outlines of the three principal physiographic divisions of Arizona.

the Globe quadrangle, which lies between the meridians 110° 45′ and 111° 00′ west longitude and the parallels 33° 15′ and 33° 30′ north latitude. It is thus a sixteenth of a square degree of the earth's surface and contains about 250 square miles. It is situated in the southeast-central part of the Territory of Arizona, between the Gila River on the south and the Salt River on the north, and includes portions of Gila and Pinal counties. The town of Globe, with a population of about 1,500, lies near the eastern edge of the quadrangle and is the terminus of the Gila Valley, Globe and Northern Railway, a branch line about 130 miles in length, which connects with the Southern Pacific Railroad at Bowie.

The principal drainage is northward through Pinal and Pinto creeks into the Salt River, but a relatively small area along the southern edge is tributary to the Gila River.

The position of the Globe quadrangle and the approximate boundaries of the physiographic divisions of Arizona, presently to be described, are shown in the index map, fig. 1

LITERATURE.

The following list is not intended to be an exhaustive bibliography, even of that part of Arizona included within the Globe quadrangle. It aims merely to enumerate those works which contain some substantial contribution to the geology or to the history of mining development of central Arizona. As in the case of most mining regions, Globe has supplied the theme for much writing of no permanent value. While diligent culling of this evanescent literature may occasionally be rewarded by the discovery of some fact of historical interest, the search has little to enliven its dreariness, and a list of such contributions can serve no useful purpose. Many general publications on Arizona, containing occasional references to the mines of the Globe region, have also been intentionally omitted.

ANTISELL, THOMAS. Explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean, 1853–1856, Vol. VII, Washington, 1857, Part II, Geological Report, pp. 139–166, Plates X–XII.

Describes the geology along the Gila River from Yuma to the Rio San Pedro, and gives brief notes on the materials and structure of the "Catarina" (Catalina), "Calitro" (Caliuro) Pinaleño, Chiricahua, Peloncillo, and Mogollon ranges in southeastern Arizona.

NEWBERRY, J. S. Report upon the Colorado River of the West, explored in 1857–1858, by Lieut. J. C. Davis, Washington, 1861, Part III. Geological Report, p. 42.

First recognition of sandstones resting on granite in the Grand Canyon. Refers them to the Potsdam and reports Silurian, Devonian, and Carboniferous rocks as conformably overlying them.

PUMPELLY, R. Mineralogical sketch of the silver mines of Arizona: Cal. Acad. Sci., Proc., Vol. II, 1863, pp. 127–139.

Notes parallelism of mountain ranges and extensive development of "Quaternary" gravels in central Arizona.

GILBERT, G. K. On the age of the Tonto sandstone: Wash. Philos. Soc., Bull., Vol. I, 1874, p. 109. (Brief abstract.)

Considered as probably primordial Silurian.

MARVINE, A. R. Geology of route from St. George, Utah, to the Gila River, Arizona: U. S. Geog. and Geol. Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1875, pp. 193–225, Plate IV.

Describes boundary region between Colorado Plateau and Basin Range system. Describes and figures geological section from Camp Apache to Florence, across Apache and Pinal ranges.

GILBERT, G. K. Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872: U. S. Geog. and Geol. Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1875, pp. 21–187.

Describes relation of basin ranges to the Plateau Region from Nevada and Utah as far as Fort Apache. Characterizes basin range structure. Describes gravels of the valleys.

GILBERT, G. K. Report on the geology of portions of New Mexico and Arizona, examined in 1873: U. S. Geog. and Geol. Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1875, pp. 507–567.

Distinguishes three natural divisions in Arizona—the Range region, the Volcanic region, and the Plateau region. Describes in general the geology and structure of each region in southeastern Arizona. Names, describes, and discusses the Gila conglomerate.

POWELL, J. W. Report on the geology of the eastern portion of the Uinta Mountains, etc., Washington, 1876.

Describes stratigraphy and orography of the Plateau and Basin provinces.

HINTON, R. J. The Handbook to Arizona, San Francisco, 1878.

Contains historical data in regard to early mines and development.

DUTTON, C. E. Tertiary history of the Grand Canyon district: Monograph U. S. Geol. Survey, Vol. II, Washington, 1882.

This work, while not directly touching central Arizona, describes the Great Colorado Plateau, and is invaluable in contributing to that comprehensive view of the geology of the territory which should precede any detailed study of a limited area.

BLAKE, W. P. Geology of the Silver King mine: Engineering and Mining Jour., Vol. XXXV, 1883, pp. 238–239, 254–256, 270–271.

Historical notes on Globe region. Geological sketch of district in vicinity of the Silver King mine, west of the Globe quadrangle.

WALCOTT, C. D. Pre-Carboniferous strata in the Grand Canyon of the Colorado, Arizona: Am. Jour. Sci. (3), Vol. XXVI, 1883, pp. 437–442.

Presence of Devonian shown between the Red Wall (Carboniferous) and the Tonto (Cambrian), Chuar and Grand Canyon groups described as unconformably below the Tonto and probably Lower Cambrian.

HAMILTON, PATRICK. The Resources of Arizona, 3d ed., San Francisco, 1884, pp. 143–245.

An account of mines and mining, containing much historical information.

WENDT, ARTHUR F. The copper ores of the Southwest: Trans. Am. Inst. Min. Eng., Vol. XV, 1886–87, pp. 60–68.

Describes the Globe (now the Old Dominion) and the Black Copper mines in the Globe district. Refers the limestone of the former mine to the Carboniferous.

DOUGLAS, JAMES. The copper resources of the United States: Trans. Am. Inst. Min. Eng., Vol. XIX, 1891, p. 689.

Brief reference to the Globe district.

WALCOTT, C. D. Correlation papers—Cambrian: Bull. U. S. Geol. Survey No. 81, pp. 220–221.

Summarizes and reviews history of opinion on the Tonto group of Arizona. Considers the group Cambrian.

VAN HISE, C. R. Correlation papers—Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, pp. 326–332. 1892.

Summarizes literature of pre-Cambrian in Arizona.

GILBERT, G. K. Geological excursion to the Rocky Mountains, Albuquerque to Flagstaff: Congrès Géologique International, Compte Rendu, Fifth Session, Washington, 1893, pp. 469–470.

Describes briefly the Colorado Plateau.

WALCOTT, C. D. Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1894, pp. 497–519.

Reviews literature on the older rocks of the Grand Canyon. Divides them as follows:

Cambrian	Tonto	
	Unconformity	
Algonkian	Grand Canyon	Chuar Unkar
	Great unconformity	
	Vishnu	

Describes the Chuar and Unkar groups. Discusses geological age and correlation.

WALCOTT, C. D. Algonkian rocks of the Grand Canyon of the Colorado: Jour. Geol., Vol. III, 1895, pp. 312–330.

Slightly condensed from preceding paper.

DOUGLAS, JAMES. The copper industry of Arizona: Mineral Industry, 1897, pp. 231–232.

History and general character of ores of the Globe district.

BLAKE, W. P. Mining in Arizona: Report of the governor of Arizona to the Secretary of the Interior, Washington, 1899, pp. 43–109.

Historical sketch. Notes on the condition of various mines in the year 1899.

EMMONS, S. F. The secondary enrichment of ore deposits: Trans. Am. Inst. Min. Eng., Vol. XXX, 1901, pp. 192–193.

Brief account of the occurrence of the copper ores in the Old Dominion mine.

THOMAS, KIRBY. The Globe mining district, Arizona: Mining and Metallurgy, Vol. XXIV, 1901, pp. 231–232.

Brief notes on history and production.

OUTLINE OF THE PHYSIOGRAPHY OF ARIZONA.

As the detailed investigation of the comparatively small area with which this report is concerned did not permit of extensive general reconnaissance the following sketch is necessarily in greater part a compilation, based upon the geological literature which has been brought together in the foregoing pages. It is intended to recall to the reader's mind the salient topographic features of a great region and to supply a setting into which to fit the more detailed characterization of a district that is but a very small part of the whole.

The Territory of Arizona may be divided into three physiographic regions, which are very rudely outlined in fig. 1, on page 10. The first of these, occupying the northeastern portion of the Territory, is included within the Colorado Plateau, that wonderful province which the writings of Powell, Gilbert, and Dutton have made classic ground in geology. This division, which within the boundaries of Arizona has an area of about 45,000 square miles, drains northward through the Colorado Chiquito (Little Colorado), Rio Puerco, and smaller streams into the Grand Canyon of the Colorado. Its southwestern limit traverses the Territory in a general southeasterly direction from the Grand Wash, near the eastern border of Nevada, to the New Mexico line, a few miles northeast of Clifton. This limit is not everywhere clearly defined. For about 240 miles, extending from the mouth of Diamond Creek on the Colorado River to the vicinity of Fort Apache, the edge of the plateau is marked, according to Gilbert,[a] by the continuous line of the Aubrey cliffs, which divide the waters of the Colorado Chiquito from the Gila. These cliffs are well shown at the southwestern edge of the Mogollon Mesa, where they form an abrupt scarp from 1,000 to 2,000 feet in height,[b] overlooking Tonto Basin and facing the Mazatzal and Ancha ranges. From Fort Apache eastward to the New Mexico line the plateau boundary is less distinct. Vast accumulations of volcanic rock have obscured the plateau surface and erosion has partly destroyed its continuity.[c] The San Francisco, Mogollon, Blanca (White), and Escudillo mountains are described by Gilbert[d] as volcanic masses resting upon the general plateau surface.

Describing this surface, Dutton[e] says:

"Its strata are very nearly horizontal, and with the exception of Cataract Canyon and some of its tributaries it is not deeply scored. Low mesas gently rolling and usually clad with an ample growth of pine, piñon, and cedar; broad and shallow valleys, yellow with sand or gray with sage, repeat themselves over the entire area. The altitude is greater than the plateaus north of the chasm except the Kaibab, being on an average not far from 7,000 to 7,500 feet. From such commanding points as

[a] Wheeler Survey, Vol. III, 1875, p. 47.
[b] Topographic Atlas U. S., Verde sheet.
[c] Gilbert, loc. cit., pp. 525-537.
[d] Loc. cit., p. 542.
[e] Tertiary history of the Grand Canyon district: Mon. U. S. Geological Survey Vol. II, 1882, pp. 14-15.

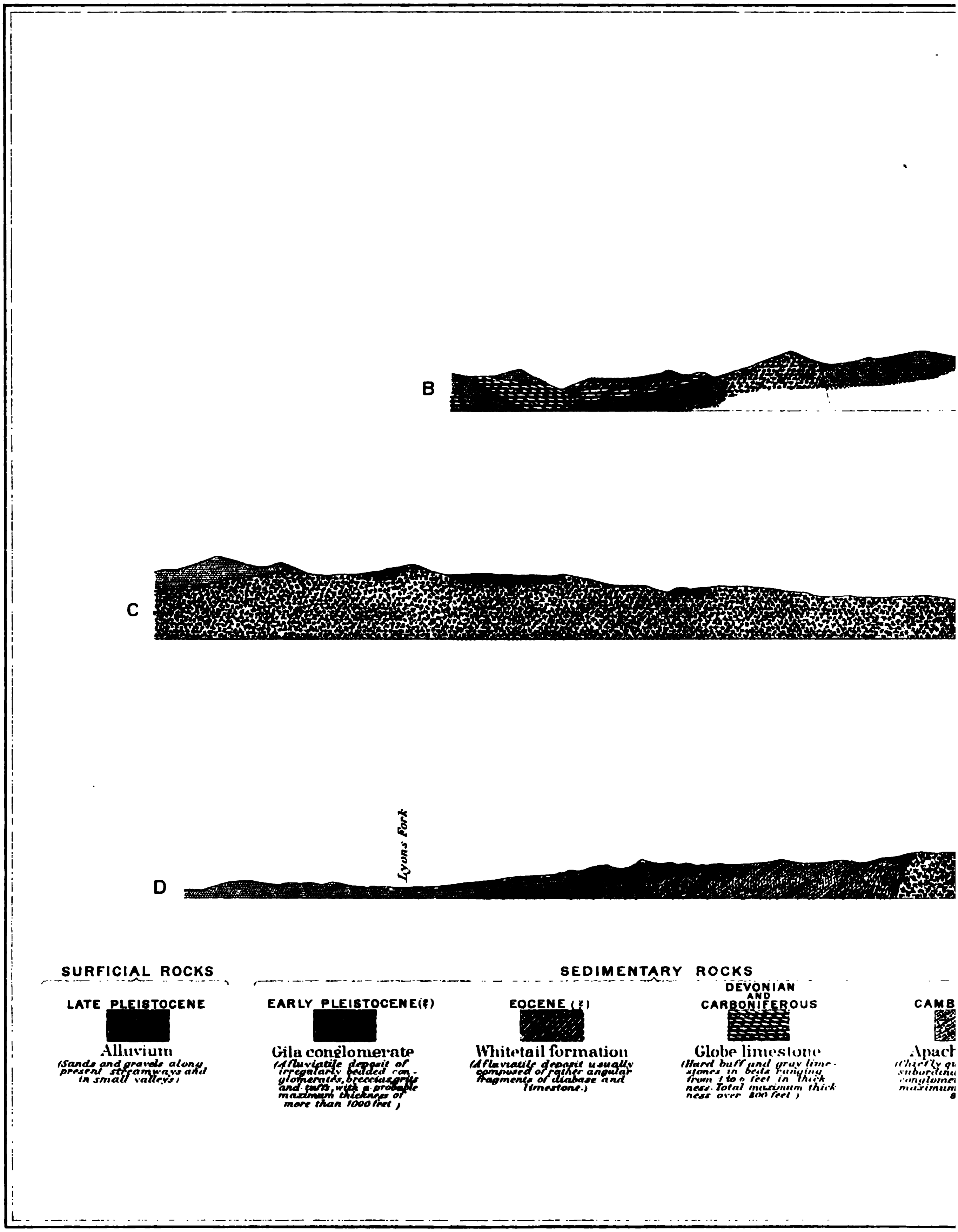
give an overlook of this region one lonely butte is always visible and even conspicuous by reason of its isolation. It stands about 20 miles south of the Kaibab division of the Grand Canyon, and is named the Red Butte. It consists of Permian strata lying like a cameo upon the general platform of the Carboniferous beds. The nearest remnant of similar beds is many miles away. The butte owes its preservation to a mantle of basalt which came to the surface near the center of its summit. It is an important factor in the evidence upon which rest the deductions concerning the great erosion of this country.

"Fifty or 60 miles south of the river rise the San Francisco Mountains. They are all volcanoes, and four of them are of large dimensions. The largest, San Francisco Mountain, nearly 13,000 feet high, might be classed among the largest volcanic piles of the west. Around these four masses are scattered many cones, and the lavas which emanated from them have sheeted over a large area. The foundation upon which they are planted is still the same platform of level Carboniferous strata which stretches calmly and evenly from the base of the Vermilion Cliffs for more than 150 miles southward, patched over here and there with the lingering remnants of lower Permian strata and isolated sheets of basalt. South of the San Francisco Mountains the level Carboniferous platform extends for 20 or 30 miles, and at last ends abruptly in the Aubrey Cliffs, which face southward and southwestward, overlooking the sierra country of central Arizona."

It is the rolling, partly timbered surface of this great plateau, surmounted by isolated volcanic mountains, which surrounds the traveler as he journeys across the territory from New Mexico by way of Holbrook and Flagstaff to Ash Fork, on the Santa Fe Pacific Railroad.

The second physiographic division, which may be called the Mountain region, adjoins the Plateau region on the southwest, and is essentially a broad zone of short nearly parallel ranges extending diagonally across the territory from the southeast corner northwesterly to the Colorado River. The width of this zone may be taken as from 70 to 150 miles, but as will be later seen its southwestern boundary is not capable of precise demarcation. It is characterized by numerous nearly parallel short ranges separated by valleys often deeply filled with fluviatile and lacustrine deposits. The individual ranges, such as the Dragoon, Chiricahua, Pinaleno, Caliuro, Santa Catalina, Tortilla, Pinal, Superstition, Ancha, and Mazatzal mountains rarely exceed 50 miles in length or 8,000 feet in altitude. Their general trend is nearly northwest and southeast, but near the Mexican border they become more nearly north and south, and the mountain zone as a whole coalesces with a belt of north and south ranges which extends northward through New Mexico and borders the Plateau region on the east. The northwesterly belt of Arizona is described by Gilbert[a] as continuous with the Basin Range system of Nevada and Utah, and is considered by him as exhibiting the same prevailing type of orographic structure. He states that his examinations "have

[a] Wheeler Survey, Vol. III, 1875, p. 509.



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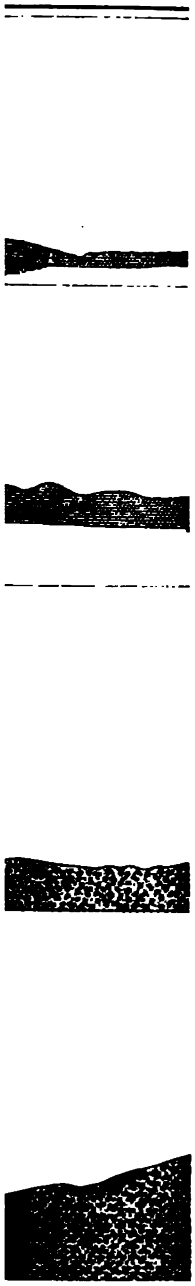

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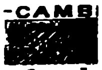

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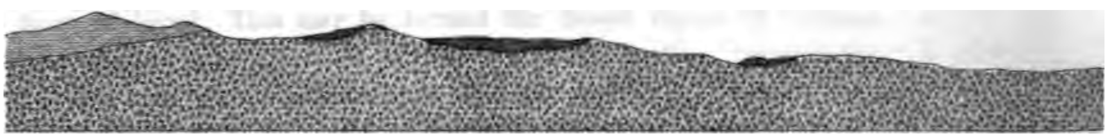


D

SURFICIAL ROCKS

LATE PLEISTOCENE

Alluvium

(Sands and gravels along present streamways and in small valleys)

SEDIMENTARY ROCKS

EARLY PLEISTOCENE(?)

Gila conglomerate

(A fluviatile deposit of irregularly bedded conglomerates, breccias, grits and tuffs, with a probable maximum thickness of more than 1000 feet)

EOCENE (?)

Whitetail formation

(A fluviatile deposit usually composed of rather angular fragments of diabase and limestone.)

DEVONIAN AND CARBONIFEROUS

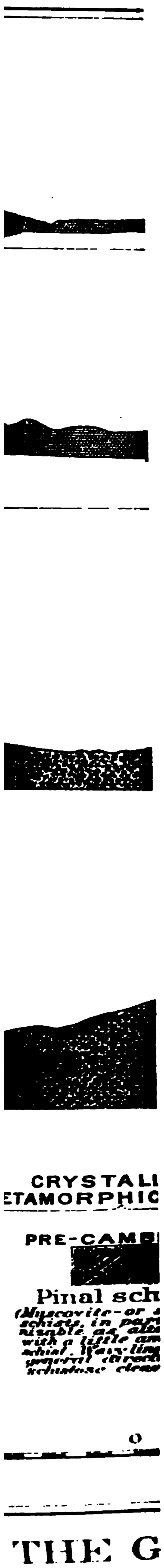
Globe limestone

(Hard buff and gray limestones in beds ranging from 1 to 6 feet in thickness. Total maximum thickness over 800 feet)

C

A

GEOLOGICAL SECTIONS



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westerly trend, and lying farther north it occupies a position en echelon with reference to the latter. Between the two ranges lies a broad valley partly filled by a thick fluviatile deposit (Gila formation), which has been dissected by the present streams into a characteristically hilly topography. Practically all of the valley included within the map drains northwestward through Pinal Creek into the Salt River, but close to the eastern border of the quadrangle the railroad crosses through a low pass (3,750 feet above sea) into the drainage basin of San Carlos Creek, a tributary of the Gila River. (Pl. III, *A*.)

The main Pinal Mountains form a bold serrate range culminating in Pinal Peak, 7,850 feet above sea and about 4,370 feet above the town of Globe, situated on Pinal Creek in the valley just described. From this peak the Mogollon escarpment, forming the southwestern boundary of the plateau region, is clearly visible some 70 miles to the north, while to the southwest the eye sweeps over the Dripping Spring and Tortilla ranges, with many subordinate rocky ridges, to where the reservoir at Florence flashes in the afternoon sun, on the border of the desert region. The range itself has been carved by erosion from a mass of nearly vertical schists invaded by extensive batholithic intrusions of granitic rock, and the resultant forms are those usually effected by atmospheric disintegration and running water upon such a mass. The process has been influenced to some extent by the difference in resistance of the various rocks. Those schists which have undergone contact metamorphism about the peripheries of the granitic intrusives are least readily worn down and consequently form most of the ridge crests and sharp summits. The granitic areas as a rule succumb somewhat more readily to erosion and consequently determine the larger canyons and the basin-like hollows such as occur in the vicinity of the Hog ranch and the Pinal and Schultze ranches. Lowest in the scale of resistance are those schists which have not been indurated by proximity to masses of intrusive rock, and which form low foothills or spurs on the flanks of the range, especially on its southwestern side.

The northeastern slope of the Pinal Range, above a line whose average altitude may be roughly placed at 4,200 feet, is abrupt and deeply scored with steep-walled V-canyons. Its spurs present the rocky and angular character usually associated with youthful and vigorous erosion of a metamorphic and intrusive complex. But below this line the topography, as is evident from a glance at the map (Pl. I), is of an entirely different kind. The general slope, descending to Pinal Creek at the rate of about 290 feet to the mile, is comparatively gentle. The main spurs, although elaborately sculptured (Pl. III, *B*), show soft, rounded contours, and are separated by long branching arroyos of very even grade. This latter topography, as will later be more fully shown, is that characteristic of the thick deposits of fluviatile material which in this region fill the valleys between the mountain ranges and lap up over the latter in long gentle slopes intricately dissected by the present streams.

Toward the southeast corner of the quadrangle the Pinal Mountains fall off rapidly to an altitude of about 5,000 feet, and are succeeded by several smaller ridges whose forms are evidently conditioned by monoclinal structure with southwesterly dip. South and southwest of Pinal Peak, in the vicinity of the old mining settlement of Pioneer, the ridges (collectively and somewhat vaguely known as the Dripping Spring Range) exhibit a topography which is strikingly controlled by a general monoclinal structure of northwesterly trend and southwesterly dip. (Pl. IV, *A*.) These ridges, carved from Paleozoic sediments and intrusive sills of diabase, show prevailingly gentle slopes to the southwest, and a series of steep slopes, benches, and scarps facing the crystalline mass of the main Pinal Range. A view over this region, which, unfortunately for the discussion of the interesting structural problems it presents, lies just outside of the Globe quadrangle, gives an impression of regularity and continuity in the several ridges which closer examination dispels. The first impression is that produced by the regularity in strike and dip and the repetition of the same type of profile in the several ridges. The final conclusion is that derived from a closer study of the underlying geological structure upon which the topography depends, and which is elsewhere discussed in this report.

Toward the southwest and west the slopes of the main Pinal Range descend to the Dry Wash of Mineral Creek, showing a similar but scarcely so well marked a change in topography as was described on the northeastern side of the mountains. The fissile schists, of which the greater part of this slope is composed, are associated with a rather intricately modeled surface of small spurs and ravines, which passes with no very noticeable change into the topography produced by the erosion of the Gila formation along Mineral Creek. On the west side of the Dry Wash of Mineral Creek the older rocks are buried beneath a great flow of dacite, whose surface, while forming in its larger aspect a gentle slope showing only moderate dissection, is so exceedingly rough and rocky as to be generally impassable for horses and traversable on foot only with much difficulty.

Toward the northwest the Pinal Mountains decrease in altitude to the hilly granitic basin inclosing the Schultze ranch. From this ranch northwestward to the bounds of the quadrangle, between the northward-flowing Pinal and Pinto creeks, is an area of crowded hills showing no apparent regularity of form or arrangement. The highest of these is Webster Mountain, and like Sleeping Beauty and other prominent knobs in this vicinity it is capped with dacite. To the presence of the same capping is also due the flat mesa-like character of

A. THE TOWN OF GLOBE, FROM THE NORTH.

In the distance is the Graham or Pinaleno Range. The town lies along Pinal Creek, which is entrenched in the Gila conglomerate. Just to the left of the center of the picture is the low pass whence the railroad descends to the Gila River, which flows westward past the northern end of the Pinaleno Range.

B. VIEW TO THE SOUTHEAST FROM THE NORTH SIDE OF WEBSTER GULCH, SHOWING TOPOGRAPHY CHARACTERISTIC OF THE GILA CONGLOMERATE.

Hills in foreground are composed of Pinal schist and dacite. On the right appear some of the northeastern spurs of the Pinal Range. In the distance, rising above the dissected deposit of Gila conglomerate, is the Pinaleno Range.

some of the higher ridges, whose tops are usually exceedingly rugged in detail and are often bounded by precipitous slopes or cliffs, due to erosional sapping. As a whole the topography of this portion of the quadrangle is rather minutely and irregularly diversified, and as will be later shown this is the direct consequence of deep erosive etching upon complexly faulted heterogeneous rocks. By this faulting the country has been broken into countless small blocks, and in the subsequent wearing down of the region each block has been to a large extent a unit, influencing by its position and structure the destroying agencies at work upon its exposed portion. This complex of hills is underlain by granite, of which considerable areas are exposed. The characteristic topographic expression of areas where this rock forms the surface is that of an undulating or hilly lowland, surrounded by ridges of the other rocks.

In the northeastern corner of the quadrangle lies a region of hills, within which may be distinguished two minor topographic divisions. The first of these, in the extreme corner of the quadrangle, consists of a series of northwest-southeast ridges composed mainly of quartzite, with a prevailing southwest dip. They are essentially strike ridges in which the same beds are partly repeated by faulting. Between these ridges and Pinal Creek is a zone about 3 miles broad within which the valleys and relative lowlands are carved in diabase, while the ridges and most of the higher hills are composed in their upper portions of quartzite resting with intrusive contact upon the diabase. As in the region north of Schultze ranch, the topography is irregular, and is intimately related to the geological structure, as will be shown in a succeeding section. The hills northeast of Globe may all be regarded as the lower southwestern foothills of the Apache Mountains, and may be conveniently called the Globe Hills.

The topography characteristic of areas underlain by the Gila formation has already been noted in connection with the description of the northeastern flanks of the Pinal Mountains. Its intricate modeling and yet smooth rounded contours (Pl. III, *B*) are found, with one or two local exceptions, wherever this formation occurs. They are the notable features in the landscape in the immediate vicinity of Globe, northward along Pinal Creek, about Miami Flat and Russell Gulch, near the head of Webster Gulch, along portions of Pinto Creek, and elsewhere.

No account of the topography can be considered complete without some reference to the stream channels or arroyos. The larger ones, such as Pinal, Pinto, and Mineral creeks, have broad sandy or gravelly beds of very even grade (Pl. IV, *B*). This evenness of grade is not as a rule confined to open country, but persists even where the streams, such as Pinto Creek, have cut deep canyons through hard rocks. Rock in place is very rarely exposed in the bottoms of these channels, and being generally dry for much of the greater part of the year, they form the natural roads of the region. Even in the canyons it is usually found that existing obstructions to travel are due to fallen masses of rock rather than to falls or inequalities in the stream bed itself. The tributaries of the main creeks exhibit similar characteristics on a smaller scale, and as a rule it is not until the steeper headwater ramifications of an arroyo are reached that rock in place appears in its bed, and travel becomes more difficult. This regularity of grade and absence of rocky bottom are particularly noticeable in all the important channels which have trenched the conglomeratic beds of the Gila formation.

CLIMATE AS RELATED TO GEOLOGICAL PROCESSES.

The control imposed by climatic conditions upon the geological processes of denudation and degradation which are immediately concerned in sculpturing the hills and in producing those varied details of form which characterize the scenery of a given district is nowhere more strikingly shown than in those arid countries of which the Globe region furnishes an example. With the exception of the upper slopes of the Pinal Mountains, which from their elevation enjoy a larger share of moisture and more luxuriant vegetation than falls to the lot of the country stretching away from their flanks, the Globe quadrangle is typically arid. Complete meteorological records are not available for any part of the quadrangle. Reports made to the Weather Bureau from Globe for the year 1894 show a mean annual temperature of 64.3°, with an extreme range from 21° in January to 108° in July, and a total precipitation of 12.87 inches. A record of precipitation has been kept for over ten years at the Pinal ranch, near the western edge of the quadrangle, and shows an average of about 20 inches—probable considerably more than falls in the vicinity of the town of Globe. At San Carlos, about 25 miles southeast of Globe, records for a decade past show a mean annual temperature of about 64°, a maximum temperature of 117°, and a minimum of 1°. The average annual precipitation at San Carlos during this period was about 11 inches. At Florence, about 40 miles southwest of Globe, the mean annual temperature is about 68.5°, the winters being apparently somewhat warmer than at San Carlos. As the elevation of Globe is 1,000 feet greater than that of the latter place, its summers are probably somewhat cooler, the maximum at Globe in 1894 being 108° as against 111° at San Carlos. The hottest weather at Globe is usually during June and July.

Throughout this part of Arizona a considerable proportion of the scanty annual precipitation falls in the form of rain during the sudden and violent downpours which are common in July and August. The effect of these rains is to wash the loose detritus down the hill slopes and to fill the dry stream beds with

GENERAL GEOLOGY.

PRELIMINARY OUTLINE.

The oldest rocks occurring within the Globe quadrangle are crystalline schists of pre-Cambrian age. These represent ancient sediments which, prior to the deposition of the lowest Cambrian rocks known in this region, were upturned, compressed, intruded by granitic rocks, and metamorphosed to their present crystalline condition. They will be called the Pinal schists. It is highly probable that at the close of this pre-Cambrian revolution the region was characterized by a mountainous topography. But of this no evidence remains to-day, other than can be inferred from the structures and textures of the pre-Cambrian rocks. It is certain that a long period of denudation and degradation reduced this crystalline basement to a fairly even surface or peneplain, upon which the next younger rocks were deposited.

These later rocks comprise shales, conglomerates, and quartzites, with a local thickness of from 500 to 800 feet. No fossils have been found in these beds, but they are thought to be probably Cambrian in age, corresponding to the Tonto group of the Grand Canyon section. This entire assemblage of shales, conglomerates, and quartzites will be referred to as the Apache group.

Overlying the Apache group is a series of limestones with an observed maximum thickness of about 400 feet. These limestones are fossiliferous, and their age is thereby determined as ranging from Devonian to Upper Carboniferous. But it was found impracticable to consistently divide and map them as two or more formations, and they will accordingly be treated as a unit and referred to as the Globe limestone. The reasons for this procedure are fully given in the sequel.

Although no convincing evidence of unconformity was obtained, even in excellent exposures, it is probable that an erosion interval separates the Globe limestone from the Apache group.

The original top of the limestone section is nowhere preserved within the Globe quadrangle. If it was once covered by Mesozoic sediments, all trace of them has been removed. The Globe limestone, so far as the Globe quadrangle is concerned, closes the record of marine sedimentation. During the long geological interval between the close of the Upper Carboniferous and the extensive effusive eruptions of dacite which are provisionally referred to the early Tertiary, occurred the second great deformation of the region imposing upon it structures responsible in large measure for the features of the present topography. The Paleozoic sediments and their underlying crystalline basement were cut by hundreds of faults. Following or accompanying the faulting large masses of diabase were intruded, chiefly in the form of sills between the sedimentary beds of the fault blocks.

The intrusion of the diabase was followed by long-continued erosion, during which the rocks were further faulted and the original sulphide ores deposited. After this period of erosion, which reduced much of the region to very moderate relief, the volcanic energies again manifested themselves through extensive eruptions of dacite, which appears to have covered all of the area with the exception of the higher portions of the Pinal Mountains. The vents through which the dacite was erupted have not been identified, but the rock is known to have a distribution far beyond the Globe quadrangle to the north and west. The time of the volcanic eruption may be tentatively referred to the early Tertiary, but the Globe region affords no known facts upon which to base a more precise date.

After the dacitic eruption, the region was again deformed by extensive normal faulting. The rocks, traversed by numerous faults, were carved into nearly their present topography and the waste deposited in the valleys as a variable fluviatile accumulation, which has been termed the Gila conglomerate. The age of this conglomerate can not be exactly determined. It is probably early Pleistocene, or possibly late Tertiary. During its deposition there was at least one eruption of basalt.

The Gila conglomerate has also been faulted, and is generally well dissected by the present arroyos or stream channels, as a result of some regional change, either of elevation or of climate.

CRYSTALLINE METAMORPHIC ROCKS.

PINAL SCHISTS.

Occurrence and distribution.—The Pinal schists, broken by granitic intrusions into very irregular masses, are abundantly present and well exposed in the Pinal Mountains, whence their name is derived.[a] The largest single body of schistose rocks is that underlying the greater part of the western slope of the range, stretching out ragged tongues over its crest and extending down beneath the Gila formation at the northwest foot of the mountains. Another considerable area is found near the southeast corner of the quadrangle, partly bounded on the southeast by a fault.

As a rule the schists are separated by intricate boundaries from the granitic rocks (Madera diorite, Schultze granite, etc.), which have irregularly invaded them. Masses of schist, ranging in size from those measurable in inches to those most

[a] The Pinal schists of this report probably correspond to the Arizonian slates of Blake. See Geology of the Silver King mine: Engineering and Mining Journal, Vol. 35, 1883, pp. 238–239.

conveniently expressed in miles, are often entirely surrounded by the eruptive rock, and in the Madera diorite these inclusions are frequently so small and so numerous that it is impracticable to delineate schist and eruptive separately on a geological map. The practice in such cases has been to map the inclosing granitic rock and to outline only those areas of schist which are of sufficient size and individual importance to appear on a map of the scale used. The great local abundance of schist fragments included in the Madera diorite may be well seen along any of the various roads that ascend the northeastern slope of the mountains.

As the schists near the contact with the Madera diorite are usually highly crystalline resistant rocks, they are less readily degraded than the eruptive rock under similar conditions of erosion, and, as a consequence of their greater durability, frequently stand out as ridges and spurs, while the canyons and basins are more commonly excavated in quartz-mica-diorite or granite. This relation is, however, partly due to the fact that the granitic rock as a whole underlies most of the schist, and the exposures of the latter become less extensive as the whole range is degraded.

As might be expected in rocks so intricately intruded by batholithic granitic masses, the Pinal schists show variable strikes and dips. They are least disturbed or contorted in the broad belt between the Hog ranch and Hutton Peak and between Lyons Fork and the main branch of Mineral Creek. In this area regularly laminated sericite-schists, containing some bands in which the original character of quartzose grits is distinctly recognizable, predominate, but change to more coarsely crystalline muscovite-schists as the Madera diorite is approached. The prevailing strike of the schistose cleavage in this and in other schist areas of any considerable size is northeasterly and southwesterly. The dip varies from 45° to vertical, and is generally to the northwest. In smaller masses, included in granite and granitic rocks near the contact of the latter, strike and dip are often very variable. As a rule the schistosity is roughly parallel with whatever larger banding, due to differences in composition of the schists, may be discernible. This fact is accepted as an indication that the schistosity is approximately parallel with the original bedding planes of the rocks. It is noteworthy that the strike of the schistose cleavage runs nearly at right angles to the dominant trend of the present mountain ranges of the region.

The extensive intrusive mass of Schultze granite which stretches from Bloody Tanks Wash southwestward to the Pinal ranch separates the schists of the main Pinal Range from several smaller areas to the north, which together constitute a very irregular and interrupted belt extending from Black Warrior southwestward to Powers Gulch.

The schist of these northern areas is lithologically similar to that of the main Pinal Range, but the folia are much more distorted, and the rock is often so thoroughly shattered as to resemble a fault breccia. With the exception of the area just east of Bloody Tanks and that south of Gold Gulch, it is rarely possible to detect any regular strike and dip of the schistosity. Good exposures of this crumpled, shattered schist may be seen along Webster Gulch, particularly near Black Warrior and the Black Copper mine; near the head of Liveoak Canyon and on Pinto Creek.

The brecciation of the schist probably dates in part to an early period. At that time the schist laminæ were crumpled and broken, apparently under slight superincumbent load, and the open more or less lenticular spaces formed between the contorted laminæ were filled with quartz. The result was a fragile rock, full of small surfaces of weakness, which was thoroughly shattered by later movements, such as the postdacitic faulting of the region.

An isolated mass of Pinal schists occurs 4 miles a little east of north from Globe. This area is surrounded by diabase, from which rock it is very probably separated on all sides by faults.

Petrography.—With the exception of occasional bands of greenish amphibolite, later to be described, the Pinal schists are generally rather light gray in color, with frequently a silvery satiny luster. In texture they range from cryptocrystalline slaty sericite-schists, through fine granular fissile rocks of somewhat sugary texture, to imperfectly cleavable, highly crystalline muscovite-schists. The sericite-schists, with their regular cleavage and inconspicuous crystallization, are characteristic of the larger schist areas at some distance from the Madera diorite contact. The coarser, more conspicuously crystalline muscovite-schists are found near the contact, and in masses of schist inclosed by the granitic rock.

In spite of much variety in coarseness of crystallization, cleavability, and megascopical appearance, the Pinal schists when studied microscopically show great mineralogical simplicity and uniformity. They are essentially aggregates of quartz and muscovite (including the minutely crystalline variety, sericite), with usually a little microcline or plagioclase, and small amounts of iron ore, zircon (magnetite or specularite), tourmaline, hornblende, biotite, and chlorite. Andalusite and sillimanite are abundant in certain contact facies near the granite, but are not generally present.

As a typical example of the sericite-schist there may be described a specimen collected on the trail to Lyons Fork, 2 miles southwest of the Hog ranch. This rock is bright gray, with a beautiful satiny sheen, and is cryptocrystalline in texture. It cleaves readily into thin flakes and shows small greenish knots, or "knoten," about 2 millimeters in size, dotting the lustrous cleavage surfaces.

Under the microscope it appears as a clear crystalline aggregate of allotriomorphic quartz grains and small scales of muscovite (sericite), the two minerals being present in nearly equal amount. A thin section cut across the schistose cleavage shows that this structure is due to the concentration of the quartz and muscovite in alternating microscopical bands or layers. Small granules of opaque black iron ore (probably magnetite) are scattered rather abundantly through the principal minerals, while little bunches of green, obscure, fibrous minerals, either amphibole or chlorite, and occasional minute prisms of tourmaline and rounded crystals of zircon, complete the list of mineral constituents. Microcline, sometimes abundant in the more coarsely crystalline schists, is here absent.

Among the sericite-schists on the western slope of the Pinal Range between the Hog ranch and the Dry Wash of Mineral Creek occur certain bands which, while schistose, preserve in great part the original texture of siliceous grits. The small pebbles, principally quartz, still retain their original waterworn outlines, while the finer material of the matrix has recrystallized as quartz and sericite. As far as observed these grit bands have the same strike and dip as the schistose cleavage, showing that the secondary structure is here parallel with the original bedding.

A specimen collected 2 miles northeast of Pinal Creek, a few hundred feet from the granite, may be taken as typical of the coarser mica-schist. This is a silvery gray rock of imperfect cleavage, which on fresh fracture flashes with irregularly bounded plates of white mica generally about half a centimeter in diameter. Under the microscope the principal constituents are seen to be quartz and muscovite, with very irregular allotriomorphic boundaries. The muscovite occurs in large plates, often inclosing the grains of quartz (poikilitic structure), and as the fine-leaved microcrystalline variety known as sericite. The remaining minerals of the rock are subordinate to the quartz and muscovite. They comprise magnetite in scattered granules, plagioclase in occasional allotriomorphic grains, fibrolite and rutile (?) as acicular or capillary crystals inclosed in quartz, zircon in short rounded prisms in quartz and muscovite, and chlorite in little interstitial fibrous tufts.

Varieties of the Pinal schists in which biotite predominates over muscovite are not common. Such occur, however, on Pinto Creek, 2 miles southwest of the Schultze ranch.

Tourmaline has already been mentioned as a sparing microscopical constituent of the schists. It is occasionally present, however, in greater abundance, and in vein quartz is common in certain of the schists near the granite. This occurrence and that of the characteristic contact minerals, andalusite and sillimanite, will be again referred to when the contact phenomena of the granitic rocks are described.

Associated with the prevailing silvery-gray muscovite- or sericite-schists are occasional bands of green schist of fine fibrous texture. A specimen of one of these green schists, taken from a mass of Pinal schist surrounded by the Madera diorite 2 miles northeast of Pinal Peak, shows upon microscopical examination that its principal mineral constituents are green hornblende, quartz, and epidote, with smaller amounts of biotite, chlorite, and magnetite. The rock is an amphibolite-schist.

Origin.—The preponderance of quartz over all other mineral constituents, the still greater preponderance of quartz and muscovite together, and the general absence of calcic minerals are strongly indicative of the derivation of the Pinal schists from quartzose sediments. That at least a part of the schists are so derived is conclusively shown by the occurrence, at some distance from the intruded granitic rocks, of only partly metamorphosed beds of grit or coarse sandstone forming an integral part of the schistose series. The presence of muscovite and microcline in the schists renders it probable that these original sediments were of granitic origin—were arkose sandstones or grits similar to those of the Apache group. Their original sedimentary character is also strongly suggested by the regular banding observable in the uncontorted schists on Lyons Fork of Mineral Creek, on upper Pinto Creek, and elsewhere.

The occasional bands of amphibole-schist, on the other hand, have a mineralogical composition such as results from the metamorphism of eruptive rocks. Whether this eruptive material was originally in the form of dikes cutting the siliceous sediments, or of intercalated tuff beds, can not now be determined.

It is impossible to retrace all of the vicissitudes through which rocks so ancient as the Pinal schists have passed or to determine each step in the probably complex history of their metamorphism. There can be little doubt, however, but that the extensive intrusions of quartz-mica-diorite had much to do with the transformation from sediments to crystalline schists. The change had been affected at the time of the later intrusion of the Schultze granite (granitite), and this rock seems to have produced little if any further metamorphism of the schists.

Age.—The Pinal schists have a prevailing nearly vertical schistose structure, probably in the main parallel to original bedding planes. They are intruded by granitic rocks, and both schists and intrusive masses were degraded to a peneplain before the deposition of the Apache group upon the complex basement thus provided. The Pinal schists and the quartzites of the Apache group are thus separated by a profound unconformity, comparable with the break between the Vishnu and Grand Canyon series as described by Walcott[a] in the Grand Canyon of the Colorado. In the Grand Canyon, as in the Globe district, this unconformity

[a] Jour. Geol., Vol. III, 1895, pp. 312–330.

separates crystalline schists intruded by granite from the base of the unmetamorphosed sediments. It is concluded that the Pinal schists and the Vishnu series are assignable with very little doubt to the same geological age. They are both part of the fundamental complex of Arizona.[a] The Vishnu is doubtfully referred by Walcott, in the latest paper cited, to the Algonkian, while the Grand Canyon series, above the great unconformity and below the Cambrian Tonto group, is more certainly assigned to that period. If the Pinal schists are, as supposed, the equivalents of the Vishnu series, they are then much older than the Algonkian rocks represented by the Chuar and Unkar terranes, being separated from the latter by a great unconformity. Furthermore, as described by Powell and Walcott in the Grand Canyon and as shown by study in the Pinal Mountains, the schists of the basal complex are chiefly of sedimentary origin.

If the original definition of the Algonkian as including all pre-Cambrian sedimentary rocks[b] be accepted, then the Pinal schists belong in the Algonkian, which must be considered as embracing rocks above and below the most profound unconformity known in Arizona. It seems best therefore to refer to the Pinal schists simply as pre-Cambrian, leaving it to future investigation to determine whether the Algonkian is represented in Arizona by the Grand Canyon series, or by the Vishnu series, or by both of these series separated by an unconformity apparently as profound as any described in geological literature.

SEDIMENTARY ROCKS.

APACHE GROUP.

General character and distribution.—The name Apache group is here applied to a conformable accumulation of quartzites, arenaceous shales, grits, and conglomerates, which attain within the quadrangle a maximum thickness of from 800 to

[a] Van Hise, in his correlation paper on the pre-Cambrian rocks of North America (p. 331), has, through an oversight, included the "Grand Canyon schists" within the "Grand Canyon group" of Powell, and has thus been led to the statement that between the Vishnu series and the fundamental complex there is a great unconformity. There is no foundation in the literature of the Grand Canyon for this statement. The Vishnu series with its granitic intrusives *is* the fundamental complex of the region so far as known. It is the "Grand Canyon schists" of Powell, separated by a great unconformity from his overlying "Grand Canyon group," and was considered Archean in the earlier writings of Gilbert and Walcott.

[b] See Van Hise, The iron-ore deposits of the Lake Superior region: Twenty-first Ann. Rept. U. S. Geol. Survey, Part III, p. 317, footnote.

In this, his latest contribution to the geology of the pre-Cambrian rocks, Professor Van Hise has found it necessary to redefine the Algonkian as including "all pre-Cambrian series which are dominantly of sedimentary origin, or equivalent in age with those which are dominantly of sedimentary origin," and the Archean as comprising "rocks older than the Algonkian, which are dominantly of igneous origin, but which may include subordinate amounts of sediments." It is very evident that Professor Van Hise has been driven to this modification by the adoption of a structural rather than a lithological basis upon which to discriminate Algonkian rocks from Archean or Cambrian rocks. The actual divisions are marked by unconformities. The amended definitions thus appear as unsatisfactory makeshifts. They afford really no working basis for determination, and describe rather than define rocks which have really been grouped by other criteria finding no expression in the definitions and having no essential connection with it. In other words, the real definition which Professor Van Hise has in his mind and which he makes use of in his work are probably not those which he has published, but some which very likely have reference to unconformities. It seems very probable that increasing knowledge will yet demonstrate the futility of attempting to define great geological periods on the basis of an assumption as to the lithological character of their respective systems.

1,000 feet, and are particularly well exposed on the western face of the Apache Mountains. The group rests unconformably on the pre-Cambrian crystalline complex, and is apparently conformably overlain by the Globe limestone. The original continuity of the beds of the Apache group has been greatly impaired by faulting, by intrusions of eruptive rock, and by erosion, so that at the present time the strata occur in relatively small and often isolated blocks or masses, which in a general way are peripherally disposed about the main crystalline mass of the Pinal Mountains. In the southern half of the quadrangle the Apache group is but scantily represented, strata belonging to it occurring only in the extreme southeast corner and at the northern end of one of the ridges of the Dripping Spring Range, near the Sixtysix ranch. A short distance to the south of the quadrangle boundary, however, these beds become more prominent, forming numerous short monoclinal ridges and maintaining a general dip of about 20° to the southwest (Pl. IV, *A*).

In the northern half of the Globe quadrangle the quartzites, shales, and conglomerates of the Apache group occur in numerous small fault blocks and in masses irregularly broken and often inclosed by intrusive bodies of diabase. As a rule only a part of the whole group is represented in any one block of strata, but, as shown in fig. 2, the full local section, from the bottom of the Globe limestone down to the pre-Cambrian basement, is exposed in Barnes Peak.

In the extreme northeast corner of the quadrangle, the quartzites of the Apache group form a series of short generally monoclinal ridges through which the Apache Mountains subside into the lower elevations of the Globe Hills.

In the following description and discussion of the Apache group it is proposed to divide the only complete section found, that of Barnes Peak, which appears to be representative of the greater part of the quadrangle, into four formations. The beds occurring in the numerous fault blocks of the quadrangle will then be correlated as far as possible with the formations of Barnes Peak. In many cases the identification presents no great difficulty, but in others the proper correlation of the often fragmentary and isolated masses of Apache strata with the type section can not be satisfactorily made. The chief sources of difficulty lie, first, in the considerable lithological variation of the Apache beds within the bounds of the quadrangle, whereby conglomerates and quartzites, not always distinguishable from those in the type section, appear at unexpected places in the stratigraphical column; and, second, in the remarkable manner in which a combination of geological causes has destroyed the original continuity of the beds, producing an effect of shattering and redisposition that may not inaptly be termed kaleidoscopic. No fossils have thus far been found in the Apache group, and all correlation consequently rests upon lithological and stratigraphical grounds. It was this group of rocks that Marvine,[a] in his reconnaissance through this region in the year 1871, appears to have provisionally correlated with the Tonto group of Gilbert. Much work remains to be done before the history of the Apache group shall be fully understood and its formational units receive their final distinction and definition. The field for this investigation, however, lies, not within the greatly faulted area of the Globe quadrangle, but without its borders.

Lithology, stratigraphical sequence, and local correlation.—In considering the composition of the Apache group in detail it is necessary to distinguish at the outset the beds lying north of Globe and east of Pinal Creek from those of the rest of the quadrangle. The latter, with some few exceptions, which will later be discussed, are represented by the typical section of Barnes Peak presently to be described. The former, on the other hand, appear to correspond to the Apache

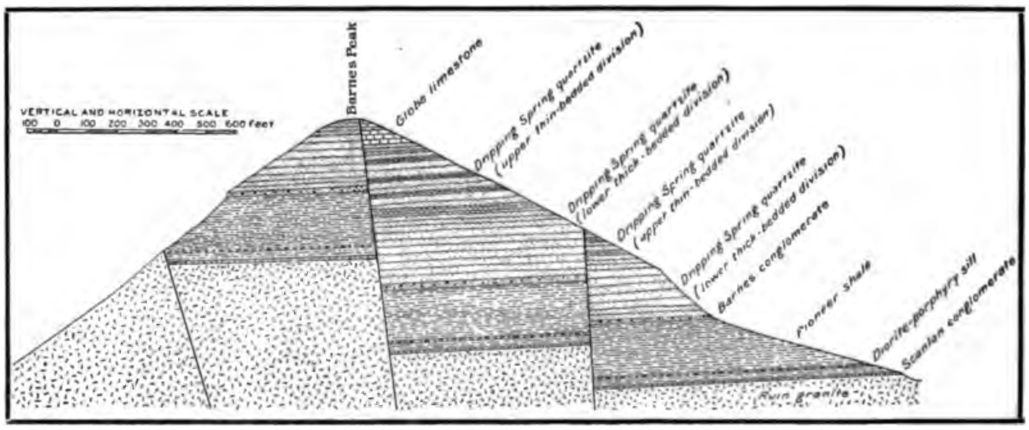


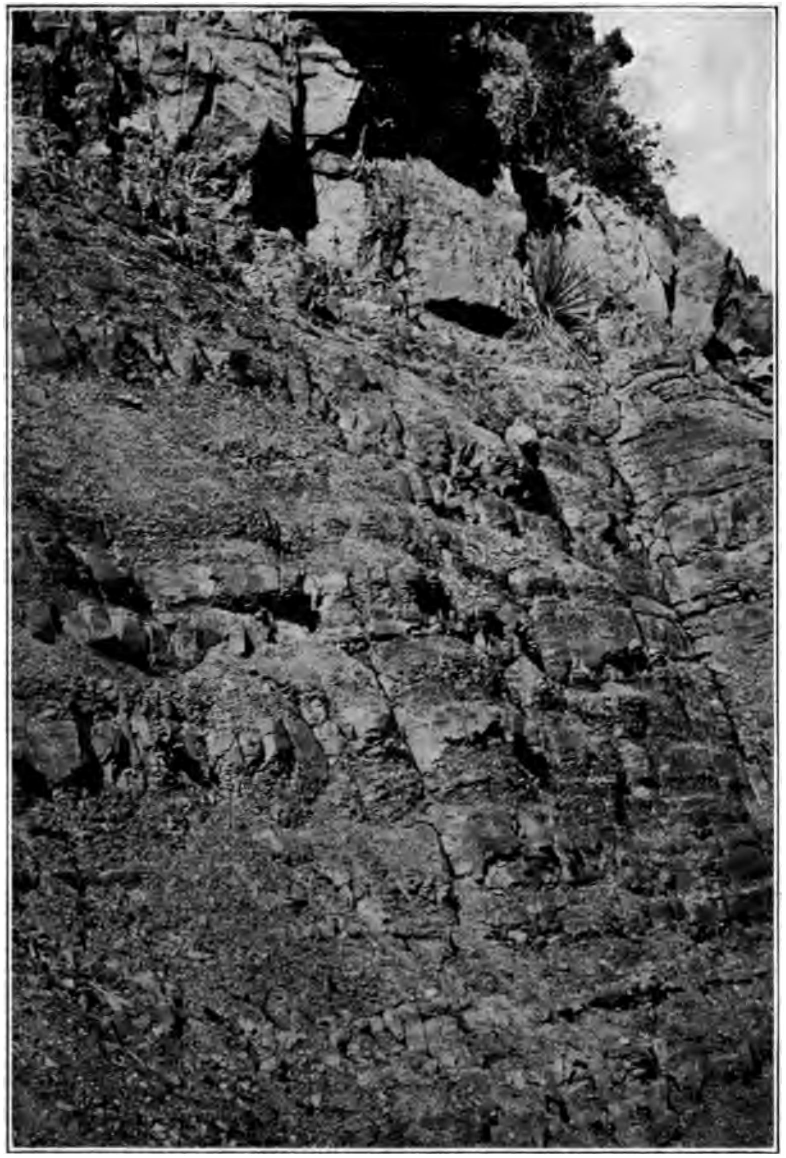
FIG. 2.—Northeast-southwest section through the northern summit of Barnes Peak, showing general stratigraphy and structure.

Mountain section, which differs from that of Barnes Peak, as will be shown in the sequel.

Barnes Peak, 5,028 feet in altitude, standing in the northwestern part of the quadrangle, is carved from several fault blocks of nearly horizontal strata which rest upon the eroded surface of the Ruin granite. The eastern slope of the hill is steep and bare and provides a complete exposure of the Apache beds from the base of the Globe limestone, a remnant of which is preserved on the top of the hill, down to the granite (see fig. 2).

The lowest bed of the group, resting upon the nearly horizontal eroded surface of the granite, is a conglomerate, varying in thickness from 1 to 6 feet. It is composed of imperfectly rounded pebbles of glassy vein quartz with an

[a] Report on the geology of route from St. George, Utah, to Gila River, Arizona: Wheeler Survey, Vol. III, pp. 221–222, 1876.



A. AN EXPOSURE OF PIONEER SHALE ON THE EAST SIDE OF BARNES PEAK.

The Barnes conglomerate is shown overlying the shale.

B. BARNES CONGLOMERATE, ON THE EAST SIDE OF BARNES PEAK.

could be chosen. It is safer, however, to adopt provisionally a name less desirable, but derived from a locality where the quartzite is known to occur. For the present, therefore, the quartzites lying between the Barnes conglomerate and the Globe limestone will be referred to as the Dripping Spring quartzite, from the Dripping Spring Mountains, a term somewhat vaguely applied but apparently embracing the monoclinal ridges south of Pioneer which owe their boldly scarped outlines to these quartzites and to the underlying Barnes conglomerate (Pl. IV, *A*).

At Barnes Peak the lower 175 feet of the Dripping Spring formation consists of massive beds of streaked buff and pink quartzite, the former being the dominant color. The beds are not sharply defined, the more massive quartzite occurring in bands 10 feet or so in thickness, which grade one into the other through rather shaly and laminated varieties. As a rule it is difficult to determine the plane where one beds stops and another begins. These quartzites and the underlying Barnes conglomerate are the most resistant portions of the Apache group, and commonly find prominent topographical expression as cliffs and cuestas.

The upper part of the Dripping Spring quartzite is characterized by thinner-bedded, hard, laminated quartzite, usually streaked with iron oxide and decidedly rusty in general appearance. These beds are apparently conformably overlain at Barnes Peak by the Globe limestone.

A graphic summary of the foregoing description of the type section for this part of the quadrangle is given in Section *A*, of Pl. VII. No fossils have yet been found in any part of the Apache group.

It is now possible to compare with the Barnes Peak section the more fragmentary sections of Apache strata in other parts of the quadrangle.

In the greatly shattered district lying north and northwest of Webster Mountain and extending beyond the northern edge of the quadrangle, little departure is observed from the Barnes Peak section, except in the varying number and thickness of the sills of decomposed diorite-porphyry intercalated in the Pioneer shale. As might be inferred from the frequent exposures of the granite basement in this faulted area, the lower beds of the Apache group predominate, although the upper beds are frequently present. The general distribution of the latter is indicated on the geological map by the areas of Globe limestone which, when not bounded by faults or cut off by intrusions of diabase, overlie the Dripping Spring quartzite. The granite in the northwestern corner of the quadrangle appears to have been worn down to an even plain prior to the deposition of the Apache group. At some points the arkose Pioneer shale is found resting directly upon the old surface with no intervening Scanlan conglomerate. Usually, however, the latter is represented by a bed, from 1 to 2 feet in

A

BARNES PE

The lower slopes, in the ravine, are on granite; above this, with no topographic break, come the Scanlan conglomerate and Pioneer shale. The Ba
Spring quartzite. The northeaste

C

VIEW FROM TOP OF NEEDLE MOUNTAIN OV

To the right of *D* is seen the Schultze ranch, surrounded by granitic hills, behind which rise the higher summits of the Pinal Range. In the midd
drainage basin of the Gila River, are the low sculptured spurs of

B

N PASS.

ver division of the Dripping Spring quartzite appear in the cliffs above, while the summit of the peak (in *A*) is composed of the upper Dripping
hown in fig. 2 is visible in *B*.

D

K AREA OF THE GILA CONGLOMERATE.

Vash may be traced from the ranch down to Miami Flats near the left of *C*. Surrounding these flats and stretching far to the south, into the
ighest on the right against the slopes of the Pinal Range.

thickness, of quartz pebbles in the usual pink feldspathic matrix. Occasionally thin bands of similar pebbles occur in the shales a foot or more above their base.

On the eastern side of Ruin Basin, near the northern edge of the quadrangle, about 200 feet of nearly horizontal Pioneer shale is overlain by the Barnes conglomerate, and the latter by about 50 feet of the Dripping Spring quartzite. A fault separates the shales from the Ruin granite on the west, so that the base of the Apache group has not been exposed.

Between Ruin Basin and Gerald's ranch the Apache beds, apparently representing chiefly that portion of the group lying above the Pioneer shale, have been considerably disturbed by irregular sill-like intrusions of diabase and by faults. Beds having the general character of the upper part of the Dripping Spring quartzite are to all appearances conformably overlain by the Globe limestone a mile and a quarter northwest of Gerald's house and both north and west of Sleeping Beauty Peak.

West of Black Warrior, in Webster Gulch, the Apache group has but fragmentary representation. Its occurrence here is of interest, however, as affording the only exposure in the quadrangle illustrating the direct relation of the group to the Pinal schists. The Scanlan conglomerate is here represented by a rather striking breccia consisting of more or less angular fragments of white vein quartz embedded in a silvery gray matrix of schist particles. This change in the material of the conglomerate from point to point shows the very narrowly defined local derivation of its materials.

Half a mile north of the Continental mine thin beds of hard red quartzite and of pink grits containing abundant particles of reddish granitic feldspar rest with gentle westerly dip upon an erosion surface of coarse reddish Schultze granite. The aggregate thickness of these beds is about 200 feet. A few inches of Scanlan conglomerate usually separates the quartzite from the granite, but is not always present. These grits and quartzites thus occupy the usual position of the Pioneer shale, and appear to be a gritty and quartzitic facies of that formation. Lithologically, however, they might readily be taken for certain of the higher beds of the Dripping Spring quartzite.

About 2½ miles southwest of the Continental mine, in the gorge of Pinto Creek, are excellent exposures of some of the upper beds of the Apache group and of the overlying Globe limestone, somewhat complicated, however, by the usual faults. The stratigraphical sequence in this locality is shown in Sections *D* and *E*, of Pl. VII. Section *D* represents the occurrence of the beds in the west wall of the canyon half a mile upstream from the edge of the quadrangle. Section *E* corresponds to the east side of the gorge about a quarter of a mile farther downstream. Both sections have at the base thin-bedded

Their position within the Apache group is as yet unknown, as their study was not carried far beyond the limits of the quadrangle.

In the southeastern corner of the quadrangle apparently the entire Barnes Peak section is represented, although the beds are much disturbed by diabase intrusions and by faults. In a general way the diabase separates the topmost beds of the Dripping Spring quartzite, which immediately underlie the Globe limestone, from the bulk of the Apache group resting upon the Madera diorite (Pl. I).

A generalized columnar section of the Apache group as represented in this part of the district is given in Section *B*, Pl. VII. This section resembles very closely the typical one of Barnes Peak. The Pioneer shale here has a thickness of about 150 feet. In some places the shales rest directly upon the worn and weathered pre-Cambrian surface of the Madera diorite, and in such cases are very conspicuously feldspathic, being made up largely of particles of pink feldspar derived from the underlying Madera diorite, the coarser particles of feldspar and quartz frequently forming well-defined grit bands near the base of the shales. At other points the Scanlan conglomerate is well developed, reaching a thickness of 5 feet. This conglomerate, however, does not everywhere rest directly upon the Madera diorite, but is occasionally separated from the latter by a coarse arkose containing fairly fresh feldspar fragments over an inch in length. This material, which is not readily distinguishable from the massive Madera diorite beneath it, reaches a maximum thickness of about 12 feet and grades insensibly into the matrix of the Scanlan conglomerate. Above the Pioneer shale comes the Barnes conglomerate, about 15 feet in thickness and crowded with well-rounded pebbles of quartz, jasper, and quartzite (Pl. VIII, *A*). The Dripping Spring quartzite overlies the Barnes conglomerate and is similar to that at Barnes Peak, although somewhat thinner bedded. (See fig. 3.)

Section *B*, Pl. VII, represents the succession of the Apache beds 2¾ miles southwest of Pinal Peak and accordingly just outside of the quadrangle. The correspondence with the Barnes Peak section is close, the most striking difference being in the presence of thick sills of yellowish decomposed diorite-porphyry. The Scanlan conglomerate moreover has here a thickness of from 6 to 10 feet and consists of well-rounded pebbles of quartz and hard compact quartzite up to 8 inches in diameter. The conglomerate rests as a rule upon the ancient reddened surface of the Madera diorite, but is locally separated from the latter by a sill of diorite-porphyry. Immediately above the conglomerate and beneath the characteristic dark-red Pioneer shales there intervene from 15 to 30 feet of light-colored highly feldspathic grits, in fairly thick beds. These grits are not developed in the vicinity of Barnes Peak.

rusty-red quartzites or sandstones, whose weathered surfaces are often dotted with little wart-like excrescences, probably due here, as elsewhere in the quadrangle, to the presence of minute nests of sericite disseminated through the mass of the rock. Within these beds, on the west side of the canyon, occurs a stratum of hard siliceous conglomerate, 6 feet in thickness, which is lacking or concealed on the east side. In both sections there appears a heavy bed, probably from 30 to 50 feet in thickness, of a rather coarse, rusty conglomerate. The pebbles of this conglomerate are principally quartzite, and appear to be lithologically identical with the reddish, warty quartzites which underlie them. No visible unconformity could be detected, however, in either section. Overlying the conglomerate are thin-bedded dark grits, sandstones, and shales, the latter occasionally showing obscure fucoid markings. On the west side of the canyon (Section *D*) these beds reach a total thickness of about 100 feet, and are overlain by a 6-foot bed of conglomerate containing some well-rounded quartz pebbles, but made up chiefly of rather angular pebbles of quartzite up to 8 inches in diameter. Immediately above the conglomerate is an intrusive sheet or sill of decomposed diorite-porphyry about 6 feet in thickness. Apparently the same sill appears in the east wall of the canyon, about 70 feet above the thick brown conglomerate. Above the diorite-porphyry, in both sections, appear hard, yellowish, thin-bedded calcareous grits, containing scattered pebbles of quartz and quartzites, and immediately underlying gray Globe limestones which contain few distinct fossils near their base.

From the preceding description it is clear that the Pinto Creek sections differ radically from that of Barnes Peak, although the two localities are only a little over 5 miles apart. The stratigraphical position of the beds on Pinto Creek, immediately beneath the Globe limestone, into which they apparently grade through some calcareous grits, is that of the upper portion of the Dripping Spring quartzite, although there are present two conglomerates not recognized in the Barnes Peak section. Some of the thick, rusty lower conglomerate was recognized on Gold Gulch, 1 mile due west of the summit of Porphyry Mountain. But between this point and Barnes Peak the more or less isolated, faulted fragments of the Apache group throw no light upon the lithological relation or gradation between the dissimilar beds underlying the Globe limestone at the two localities.

From the gorge of Pinto Creek southward the Apache group is unrepresented until the southern border of the quadrangle is reached. The small area shown on the map (Pl. I), near the Sixtysix ranch, is at the northern end of the ridge upon which, some miles to the southwest, is the mining town of Troy. The rocks here are thin-bedded reddish quartzites and red shales showing reticulated mud cracks.

Glo

Apache group

Drip
qua

Barne

Pione

Scanl
Ruin

(A) BARNES PE

1. Granitic basement ..
2. Basal conglomerate
bles, and arkose m
3. Dark red-brown aren
with thin grit beds
arkose............
4. Siliceous conglomera
rounded pebbles...
5. Massive buff and pi
ite ....
6. Thin-bedded rusty q
7. Gray limestone......

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Glob

Apache group
- Drip qua
- Barne
- Pione
- Scanl
- Ruin

(A) BARNES PE

1. Granitic basement ..
2. Basal conglomerate: bles, and arkose m
3. Dark red-brown aren with thin grit beds arkose..............
4. Siliceous conglomera rounded pebbles...
5. Massive buff and pi ite ....
6. Thin-bedded rusty q
7. Gray limestone......

Their position within the Apache group is as yet unknown, as their study was not carried far beyond the limits of the quadrangle.

In the southeastern corner of the quadrangle apparently the entire Barnes Peak section is represented, although the beds are much disturbed by diabase intrusions and by faults. In a general way the diabase separates the topmost beds of the Dripping Spring quartzite, which immediately underlie the Globe limestone, from the bulk of the Apache group resting upon the Madera diorite (Pl. I).

A generalized columnar section of the Apache group as represented in this part of the district is given in Section *B*, Pl. VII. This section resembles very closely the typical one of Barnes Peak. The Pioneer shale here has a thickness of about 150 feet. In some places the shales rest directly upon the worn and weathered pre-Cambrian surface of the Madera diorite, and in such cases are very conspicuously feldspathic, being made up largely of particles of pink feldspar derived from the underlying Madera diorite, the coarser particles of feldspar and quartz frequently forming well-defined grit bands near the base of the shales. At other points the Scanlan conglomerate is well developed, reaching a thickness of 5 feet. This conglomerate, however, does not everywhere rest directly upon the Madera diorite, but is occasionally separated from the latter by a coarse arkose containing fairly fresh feldspar fragments over an inch in length. This material, which is not readily distinguishable from the massive Madera diorite beneath it, reaches a maximum thickness of about 12 feet and grades insensibly into the matrix of the Scanlan conglomerate. Above the Pioneer shale comes the Barnes conglomerate, about 15 feet in thickness and crowded with well-rounded pebbles of quartz, jasper, and quartzite (Pl. VIII, *A*). The Dripping Spring quartzite overlies the Barnes conglomerate and is similar to that at Barnes Peak, although somewhat thinner bedded. (See fig. 3.)

Section *B*, Pl. VII, represents the succession of the Apache beds 2¾ miles southwest of Pinal Peak and accordingly just outside of the quadrangle. The correspondence with the Barnes Peak section is close, the most striking difference being in the presence of thick sills of yellowish decomposed diorite-porphyry. The Scanlan conglomerate moreover has here a thickness of from 6 to 10 feet and consists of well-rounded pebbles of quartz and hard compact quartzite up to 8 inches in diameter. The conglomerate rests as a rule upon the ancient reddened surface of the Madera diorite, but is locally separated from the latter by a sill of diorite-porphyry. Immediately above the conglomerate and beneath the characteristic dark-red Pioneer shales there intervene from 15 to 30 feet of light-colored highly feldspathic grits, in fairly thick beds. These grits are not developed in the vicinity of Barnes Peak.

It appears from the foregoing descriptions that, with the exception of the portion of the group exposed in the gorge of Pinto Creek, which can not yet be satisfactorily correlated, the Barnes Peak section is fairly representative of the Apache group as the latter occurs in the western and southern halves of the quadrangle.

In the portion of the quadrangle lying north of Globe and east of Pinal Creek the Apache group is very imperfectly represented by fragmentary masses of strata that nowhere afford a complete local section of the whole group. The nearest approach to such a section is found on the western face of the Apache

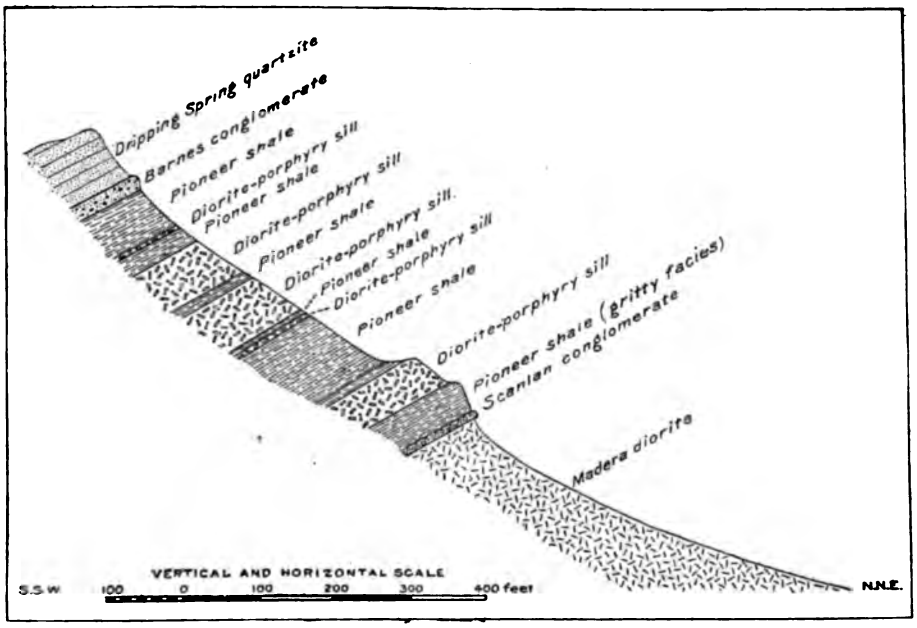


FIG. 3.—Sketch profile of cuesta fronting the Pinal Range, about 3 miles southwest of Pinal Peak, near Pioneer.

Mountains (fig. 4), and is given in conventional columnar form in Pl. VII, *C*. The lowest beds rests, as usual, upon a worn granitic surface, in this case apparently a biotite-granite. The Scanlan conglomerate, however, was not recognized. In its place are beds of hard pinkish quartzites with an aggregate thickness of nearly 200 feet. The basal bed is a tough, fine-grained, faintly striped pinkish quartzite, speckled with little greenish nests of chlorite or sericite, and containing much detrital feldspar. This is succeeded by thick beds of similar character, varying somewhat in texture, which attain a total thickness of 75 feet. Above these thick beds lie about 125 feet of thinner beds which resemble more and more the Pioneer shale until finally they pass upward with no well-defined plane of separation into beds which have all the characteristics of the latter formation. These transition beds resemble so closely some of the upper portions of the Dripping Spring quartzite, as exposed in other parts of the quadrangle, that no certain lithological criteria for their distinction were discoverable.

If the quartzite beds just described as underlying the Pioneer shale in the Apache Mountains be really the equivalent of the Scanlan conglomerate, they may be called the Scanlan quartzite. But too little work has yet been done beyond the bounds of the quadrangle to render it certain that the Scanlan conglomerate is everywhere absent beneath these quartzites, and for the present the latter will be referred to merely as "the lower quartzite."

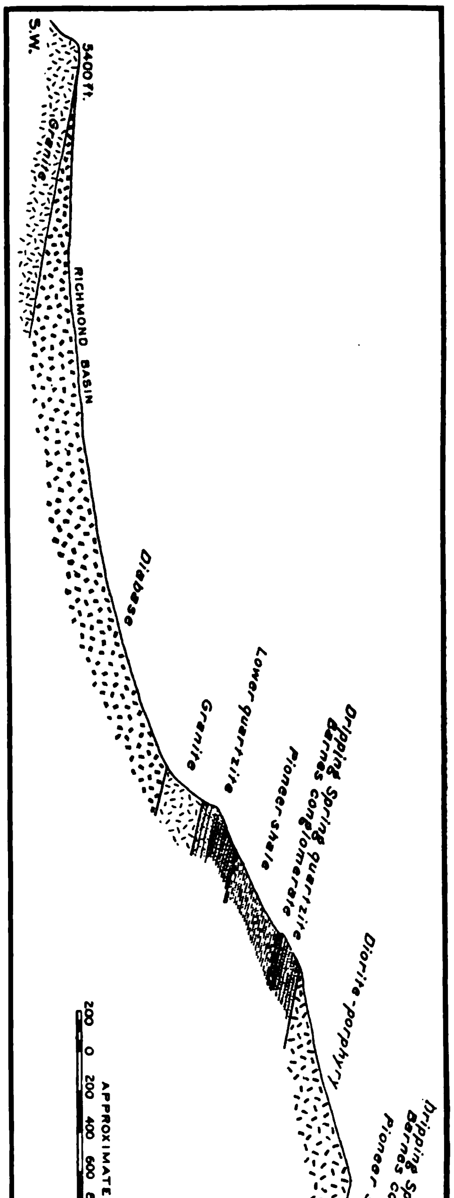


Fig. 4.—Sketch section from the summit of the Apache Mountains southwest to Richmond Basin.

The Pioneer shale reaches a thickness of about 200 feet in the Apache Mountains and exhibits the same lithological character as at Barnes Peak. It is overlain by the Barnes conglomerate, which is locally a bed of hard buff sandstone or quartzite, 15 feet thick and containing subordinate bands of well-rounded quartz pebbles. The Dripping Spring quartzite forms the crest of the Apache Range, and is represented by thick beds of buff quartzite, of which about 150 feet remain, the higher beds having been removed by erosion (fig. 4).

The striking change in the Apache group through the addition of 200 feet of quartzite below the Pioneer shale, the absence of a continuous section of the upper beds of the Dripping Spring formation, and the great disturbance due to diabasic intrusions and to faulting, combine to render impossible the satisfactory correlation of the various quartzitic masses in the northeastern part of the quadrangle. Near the northern edge of the area the "lower quartzites" are found resting in small remnants upon the Ruin granite. About the Old Dominion mine the Globe limestone is apparently underlain by rather thin-bedded quartzites of the Dripping Spring formation, while the lower, heavier beds of the same formation determine most of the strike ridges northeast of Ramboz Peak. In the extreme northeast corner of the quadrangle a little Globe limestone appears to overlie rusty grits containing quartz pebbles up to 5 millimeters in diameter. About 2 miles northeast of Ramboz Peak, which is capped by Barnes (?) conglomerate, are cherty beds, alternating with siliceous conglomerates and grits. The stratigraphical position of these cherts, grits, and conglomerates is not definitely known. It is probable that they either represent the upper part of the Dripping Spring quartzite or else are the equivalent of a part of the Globe limestone. Future study of the region east of the Globe quadrangle will probably result in finding more satisfactory sections of the Apache group and the Globe limestone, and thereby throw light upon their subdivisions and mutual relationship.

Age.—As no fossils have been found in the rocks of the Apache group, the precise age of these beds can not be determined until their stratigraphy is studied over a much broader field than that of the Globe quadrangle. There are, however, certain general considerations that indicate, although they do not fix, the geological period to which the group belongs.

As the overlying Globe limestone contains Devonian fossils, the Apache group can not be younger, and is probably pre-Devonian. As the quartzites rest unconformably upon the Pinal schists and intrusive rocks of the pre-Cambrian crystalline complex, they are evidently much younger than the latter. So far, therefore, as its stratigraphical position is concerned, the Apache group may be Algonkian, Cambrian, or Silurian. The apparent absence of fossils, however, points to the Cambrian or Algonkian rather than the Silurian, which appears to be well provided with organic remains wherever found in Arizona. At Clifton, about 90 miles easterly from Globe, Mr. Lindgren[a] has obtained a characteristic and abundant Lower Silurian fauna. As between Cambrian and Algonkian, the former seems to be the more probable. As shown by Powell[b] and later observers, the Algonkian Grand Canyon group is separated from the Cambrian Tonto group by a well-marked angular unconformity, the Tonto in places resting upon the Vishnu schists and their associated granitic intrusives. As no equivalent unconformity could be detected between the Apache group and the Globe limestone, it is probable that the former corresponds to the Tonto group rather than to the Grand Canyon group—a conclusion in general agreement with the

[a] Oral communication.

[b] Geology of the Uinta Mountains, etc., Washington 1876, p. 70.

earlier correlation of Marvine.[a] The Apache group is accordingly placed provisionally in the Cambrian. It probably corresponds in part to the Dragoon quartzites of Dumble,[b] which are reported as underlying limestones containing Devonian and Carboniferous fossils in the Dragoon, Whetstone, Chiricahua, and Mule mountains.

GLOBE LIMESTONE.

General character and distribution.—The name Globe limestone is here applied to a formation consisting almost exclusively of limestone in beds usually ranging from 1 to 6 feet in thickness. The formation rests upon the Apache group with no visible angular unconformity and attains a maximum thickness of at least 700 feet, as exposed in the canyon of Pinto Creek. Its upper limit, everywhere within the quadrangle, is a surface of erosion, the total original thickness being therefore unknown. Although the Globe limestone apparently rests conformably upon the Dripping Spring quartzite, there are some grounds, such as the absence of recognizable Silurian beds and the occurrence of the basal quartzitic breccia noted on page 40, for suspecting that the two formations are really separated by an interval of erosion. In the Grand Canyon, according to Walcott,[c] the Devonian strata, with a maximum thickness of 100 feet, rest unconformably upon the Tonto beds, but this unconformity can rarely be detected in actual exposures. As far as could be seen in the Globe district, the limestone beds are themselves conformable throughout.

The general distribution of the Globe formation is that of the Apache group, which it overlies. Natural sections, however, are even more fragmentary than in the case of the latter group, and it was found impracticable to carry over the whole area such lithological and paleontological distinctions as might occasionally be made in some of the more continuous sections.

Lithology and stratigraphical sequence.—The basal portion of the Globe limestone is lithologically varied in different parts of the quadrangle. In the canyon of Pinto Creek and in the greatly faulted region between Ruin and Granite basins the base of the formation consists of about 10 feet of calcareous grits, succeeded by gritty fossiliferous limestone which in turn are overlain by hard gray and buff limestones, with occasional bands of calcareous shales, grits, and thin-bedded quartzite. In other localities, as at Barnes Peak, north of Sleeping Beauty Peak and near the Old Dominion mine, the basal grits are absent, and gray limestone, not noticeably fossiliferous, rests directly upon thin-bedded Dripping Spring quartzite. About three-fourths of a mile north of the I X L mine the base of the Globe limestone is separated from the underlying quartzite by a

[a] Loc. cit., p. 221.
[b] Notes on the Geology of Southeastern Arizona: Trans. Am. Inst. Min. Eng., Vol. XXXI, pp. 14-19, 1902.
[c] Pre-Carboniferous strata in the Grand Canyon of the Colorado, Arizona: Am. Jour. Sci., 3d series, Vol. XXVI, 1883, p. 438.

thin bed of siliceous breccia containing angular fragments of quartzite. Wherever thick sections of the Globe limestone are exposed it is found that the alternating buff and gray limestones with subordinate grits are overlain by gray, sometimes slightly pinkish, crinoidal limestones, usually in rather thick beds, but also some cherty beds and an occasional bed of siliceous conglomerate. As a rule, however, the limestone occurs in such small faulted masses that it is rarely possible to determine the stratigraphical horizon of the beds exposed in a given block.

The least fragmentary sections of the Globe formation found have failed to show any well-defined or recognizable plane of lithological or structural distinction within the limits of this sequence of beds, among which hard, gray limestones greatly predominate.

Age and local correlation.—Fossils were found within the Globe limestone at several points, and their investigation by Prof. Henry S. Williams and Dr. G. H. Girty has shown that they range from the Devonian to the Upper Carboniferous. Unfortunately, however, no single section has been found to clearly embrace the whole formation from its base to the highest fossiliferous Carboniferous strata preserved. Professor Williams has very kindly furnished a brief note on the Devonian fauna, while Dr. Girty has rendered a similar service in regard to the Carboniferous species. These notes are here printed in full.

Devonian fossils of the Globe quadrangle, Arizona.

By Henry S. Williams.

Two collections of fossils made by Dr. F. L. Ransome in the Globe quadrangle, Arizona, were submitted to the writer November 14, 1901, and March 17, 1902, for report upon the age of the horizon represented and the list of the faunas. The collections comprise in all 10 small lots, which are designated A, B, C, etc., and labeled as follows:

A. Limestone bluff, west side of Pinal Creek, 3¾ miles northwest of Globe. Thin bed of gray limestone about 100 feet above base of exposed limestone section.

B. Same locality as A. Band of gray limestone about 15 feet above A.

C. Buff limestone about 20 feet thick, immediately overlying bed B.

D. Gray limestone, with crinoid stems, overlying C. About 40 feet thick to top of section.

E. One-quarter mile southwest of Sleeping Beauty Peak, from near base of limestones which rest on quartzite.

F. Eastern slope of 5,300-foot limestone hill, southeast corner of quadrangle.

G. Same locality as F, and probably from same bed.

A. GLOBE LIMESTONE, CONTAINING DEVONIAN FOSSILS; ON THE ROAD TO TONTO BASIN, ABOUT 4 MILES NORTH OF GLOBE.

The lower fossiliferous bed is indicated by the letter A.

B. WHITETAIL FORMATION, AS EXPOSED BY THE ROADSIDE NEAR THE CONTINENTAL MINE.

H. Limestone hill, west side of Gold Gulch.

I. Steep slope forming east side of Pinto Creek gorge on western edge of quadrangle.

J. Same locality as I. About 40 feet higher in section.

List of faunules.

	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.
1. Atrypa reticularis Linn	×	×			×	×	×		×	×
2. Productella hallana Walcott	×	×	×				×	?		×
3. Stropheodonta calvini Miller	×						×			×
4. Cyrtia cyrtiniformis (H. and W.)	×					×	×			×
5. Spirifer hungerfordi Hall			×							
6. Spirifer orestes H. and W	×					×	×			
7. Spirifer whitneyi Hall	×									
8. Reticularia fimbriata (Conrad)							×			
9. Cyrtina hamiltonensis Hall	×									
10. Martinia subumbona (Hall); cf. Sp. intima Whidborne						×	×			
11. Pugnax pugnus (Martin)							×			
12. Orthothetes chemungensis (Con.) var	×									
13. Dielasma cf. calvini (H. and W.)								×		
14. Cf. Rhodocrinus, crinoid stems and plates		×	×	×						
15. Cf. Sponge	×									

The accompanying list of species has been identified and their presence in the several faunules[a] is indicated by the checks in the vertical columns opposite the names of the species. The names by which the forms have been recognized by American authors have been used, though in several cases the forms here met with may be regarded as but varieties of species described by European paleontologists.

With the exception of the faunule H, the several faunules are probably from the same geological formation, as indicated by the species as well as by the similarity of the rock in which they are contained.

The fauna represented is the same as that from Rockford and Independence, Iowa, which as a fauna may be appropriately called the Pugnax fauna, on account of the wide distribution of *Pugnax pugnus* wherever the associated species of the fauna appears.

The fauna appears in the New York column after the Tully limestone in the fossiliferous zone preceding the typical Chemung formation, in what has been called the Ithaca formation in central New York.

[a] I. e., local faunas.—F. L. R.

Taking the first 12 species of the list, it will be noticed that they are all brachiopods. In the material examined they are the only class of organisms recognized, except the crinoid stems; the latter may have supplied the calcareous material for the limestones in which the species are preserved.

The species, or varieties of the same species, are dominant in a fauna of wide distribution in the Northern Hemisphere. Eight of the 12 species are represented in the Devonian of Nevada and Utah; 9 have been reported from the Manitoba and Mackenzie River province; all of the 12 from the Lime Creek formation of Iowa; 7 are present in the Lummaton limestone of southern England; 9 of them are reported from Russia; 5 of them are among the limited number of known Chinese Devonian species; and 6 of them have been seen in the Ithaca zone of central New York between the typical Hamilton and the typical Chemung formation.

They constitute the typical species of the Lime Creek formation of Iowa, but in New York the species are mostly rare among the species occupying the Ithaca formation.

So far as at present known, the fauna did not coexist with the typical *Spirifer disjunctus* fauna of the New York province, but in the eastern part of the State several of the dominant species of the *Tropidoleptus* fauna of the Hamilton appear in the same fossiliferous zone with these species.

As measured by the New York standard geological column, the *Pugnax* fauna is neo-Devonian in age, and is to be correlated with the epoch of the Ithaca formation.

In its general distribution in Europe it is neo-Devonian rather than meso-Devonian, and although there its species have a Carboniferous aspect, they are occasionally represented in faunas classified as of meso-Devonian age.

It is therefore appropriate on paleontological grounds to classify the formations holding the fauna in Arizona as early neo-Devonian.

HENRY S. WILLIAMS.

NEW HAVEN, CONN., *March 24, 1902.*

CARBONIFEROUS FOSSILS FROM THE GLOBE QUADRANGLE, ARIZONA.

By GEORGE H. GIRTY.

The collections from the Globe quadrangle, Arizona, referred to the writer by Mr. Ransome, contained both Devonian and Carboniferous faunas. The Devonian faunas were sent to Professor Williams, and have already been reported on. The Carboniferous faunas are as follows, the numbers and localities of the different collections being supplied by Mr. Ransome:

No. 337. Gorge of Pinto Creek, east side, about 300 feet above lowest bed of limestone exposed in creek bed. Gray limestone with some chert.

Rhombopora lepidodendroides.
Seminula subtilita.
Eumetria or Hustedia sp.

No. 339. Gorge of Pinto Creek, east side. Gray limestone overlying J in Professor Williams's list.

Productus cora (frag.).

No. 340 A. Top of limestone section, with an exposed thickness of about 400 feet, on east side of gorge of Pinto Creek. Gray limestone.

Productus (frag.), semireticulatus type.
Productus? similar to Marginifera splendens.
Spirifer sp.
Reticularia sp.

No. 340 B. About 20 feet below 340 A.

Productus semireticulatus (different from that in 444).

No. 340 D. About 250 feet below 340 B. Some shaly and cherty beds in intervening limestones.

Fusulina cylindrica.
Productus semireticulatus.
Squamularia perplexa.

No. 444 A. West side of Gorge of Pinto Creek, in little ravine, about 50 feet below dacite cap. Hard pinkish limestone in beds up to 3 feet in thickness.

Productus cora? (frag.).
Productus punctatus.
Myalina subquadrata? (frag.).
Aviculopecten sp. (frag.).

No. 444. Same locality as No. 444 A.

Archæocidaris sp.
Orbiculoidea sp.
Derbya crassa (frag.).
Productus semireticulatus.
Spirifer cameratus.
Spirifer rockymontanus.
Myalina subquadrata.
Phillipsia sp.

No. 444 B. Same locality as No. 444 A, but about 100 feet lower in section.

Rhombopora lepidodendroides.
Derbya crassa.
Productus, semireticulatus type.
Spirifer cameratus?
Spirifer boonensis?
Seminula subtilita.

No. 475. Southeast slope of Sleeping Beauty Peak, close to fault cutting off limestones on the southeast. Yellowish, highly fossiliferous bed in prevailing gray limestones.

Campophyllum torquium.
Crinoid fragments.
Productus inflatus.
Marginifera? sp.
Spirifer cameratus.
Spirifer boonensis.
Squamularia perplexa.
Seminula subtilita.

All of these faunas are clearly Carboniferous, and, on the whole, I am inclined to believe them all Upper Carboniferous, though it may be that 340 A and 337 are of Mississippian age.

GEORGE H. GIRTY.

WASHINGTON, D. C., *April 15, 1902.*

The limestone section on Pinal Creek north of Globe, from which were obtained lots A, B, C, and D of Professor Williams's note, is shown in Pl. IX, *A*, the lower fossil horizon being indicated by the letter A. Below this horizon the section exposes a thickness of about 100 feet of fairly heavy beds of gray, sometimes slightly buff, limestone, containing as far as seen no well-preserved fossils. These lower unfossiliferous beds of the Devonian section (which may possibly be pre-Devonian, although the stratigraphic sequence is apparently unbroken) are lithologically indistinguishable from similar beds occurring elsewhere above Upper Carboniferous fossils, and therein consists one of the obstacles to successful local correlation in a region of faulted fragmentary stratigraphical masses.

Between the fossil horizons A and D there is exposed a thickness of about 35 feet of gray and yellow limestones, inclosing characteristic Devonian forms and conformably overlain by about 40 feet of gray limestone containing crinoid stems. The upper limit of the section is an eroded surface covered by Gila conglomerate. It is possible, as Professor Williams points out, that the whole section is Devonian, but it was not found practicable to discover any lithological distinction between the gray crinoidal limestone and similar beds known to occur elsewhere in the Carboniferous portion of the Globe formation.

Some of the best sections of the limestones are found in the gorge of Pinto Creek, and three of these are given in columnar form in Pl. VII, *D*, *E*, and *F*. Section *E* is particularly instructive. It shows at the base a considerable development of the calcareous transitional grits, which here attain a thickness of about 75 feet and are provisionally regarded as a part of the Globe formation. Above the grits come about 130 feet of gray limestones, apparently corresponding to the similar beds underlying the fossil bed A, on Pinal Creek. Then follow 3 feet of grit and quartzite, and 50 feet of gritty limestone, fossiliferous in part but from which no satisfactory collection was made. Overlying these are about 100 feet of rather rusty limestones containing the Devonian forms listed by Professor Williams under I and J. It thus appears that the Devonian part of the Globe limestone has a probable thickness of nearly 300 feet. Above the fossil horizon J come 200 feet of gray limestones that are not noticeably fossiliferous and may be of Carboniferous age. Farther up the slope occur gray limestones carrying *Productus cora* (No. 339 in Dr. Girty's note) and therefore of Carboniferous age. There is a possibility, however, that the continuity of the section may be broken by a fault, at the point where the column *E*, (Pl. VII) is terminated, below the known Carboniferous.

In section *F*, Pl. VII, is represented a section also from the east side of the gorge of Pinto Creek, but taken at a point a little farther north. The upper 500 feet of this section is composed of gray limestones alternating with thin cherty beds and containing Carboniferous fossils. Conformably below are 20 feet of rusty red fossiliferous limestones which are probably Devonian, although no fossils were collected at this point.

It appears from the Pinto Creek sections that the Globe formation includes in its lower part at least 300 feet of Devonian strata and in its upper part at least 500 feet of Upper Carboniferous beds. No unconformity, however, has been found between the beds belonging to these different periods. While future work in the broader region about the Globe quadrangle may result in the discovery of such an interruption of sedimentation and in the consequent splitting up of the Globe limestone, it is believed that no such division is at present practicable within the area covered by this report.

The case of the Globe limestone recalls that of the Ouray limestone in Colorado, to which Cross[a] has recently called attention. The Ouray limestone, an apparent stratigraphical unit containing characteristic Devonian fossils, was at first referred wholly to that period. Later work, however, has resulted in the discovery

[a] Geologic formations versus lithologic individuals: Jour. Geol., Vol. X, 1902, pp. 234–235.

of Lower Carboniferous fossils in the upper part of this limestone unit. There is nothing as yet known that precludes the presence of Lower Carboniferous beds in the Globe limestone between the known fossiliferous Upper Carboniferous and the known fossiliferous Devonian. The absence of any recognizable unconformity within the mass of limestone strata is suggestive of uninterrupted deposition from the Devonian to the Upper Carboniferous, and consequently of the presence of some Lower Carboniferous or Mississippian. The paleontological note furnished by Dr. Girty also intimates that the Lower Carboniferous may be represented.

WHITETAIL FORMATION.

General character, distribution, and stratigraphic position.—The Whitetail formation (so named from Whitetail Gulch and Spring) is a deposit of rather coarse and often somewhat angular stony detritus that lay in the hollows of a former land surface, and with the latter was covered by the dacite eruptions. The deposit varies much both in thickness and lithological character, and where its relation to the dacite is not clearly shown can not always be distinguished from certain facies of the younger postdacitic Gila conglomerate. It appears to have accumulated particularly upon areas of diabase, and in such situations angular or very imperfectly rounded fragments of the underlying eruptive rock with occasional pebbles of limestone make up the bulk of the deposit, which is usually weathered and partly decomposed. Pl. IX, *B*, from a photograph of a roadside cutting just southeast of the Continental mine, gives a good idea of the usual appearance of the deposit. The fragments range from a fraction of an inch to a foot or more in size.

Material similar to that described and illustrated occurs on Pinto Creek, just above the gorge, both north and south of Gold Gulch and near the head of Whitetail Gulch.

Three-quarters of a mile northwest of Continental Spring excellent exposures of the Whitetail formation may be studied on the south side of a little conical hill capped with dacite. At the lowest point in the section is exposed coarse unstratified diabase detritus, containing fragments of the latter rock up to 3 feet in diameter and an occasional bowlder of limestone in a soft and usually somewhat earthy matrix. (Pl. X.) About 25 feet higher up in the section the coarse material is mingled with some sandy detritus and shows rude stratification. (Pl. X.) Still higher, the deposit becomes finer and more distinctly bedded (Pl. XI), and at the top of the 75 feet of the formation here exposed, dark sands, largely of diabasic origin, are overlain by a bed of dacite tuff. (Pl. XI.)

The other areas of the Whitetail formation shown on the geological map (Pl. I) require no special description. The deposit is nearly always found in close

A.

B.

WHITETAIL FORMATION, AS EXPOSED THREE-QUARTERS OF A MILE NORTHWEST OF CONTINENTAL SPRING.

A, Character of deposit 25 feet stratigraphically above *B*; *B*, lower portion of exposed section.

A

B

WHITETAIL FORMATION, AS EXPOSED THREE-QUARTERS OF A MILE NORTHWEST OF CONTINENTAL SPRING.

A, Shows character af deposit in its upper portion; *B*, top of Whitetail formation overlain by glassy dacite.

proximity to the dacite, for when the latter is removed by erosion, the soft Whitetail formation can not long remain, unless, like the area southeast of the Continental mine, it is protected by being faulted in among more durable rocks. Moreover, with the removal of the dacite, the underlying Whitetail formation can not in all cases be certainly distinguished from the Gila conglomerate.

Origin.—The Whitetail formation preserves the record of the operation, prior to the dacite eruptions and on a smaller scale, of forces similar to those which afterwards accumulated the sometimes lithologically indistinguishable Gila conglomerate. Apparently then as at a later date, areas of diabase tended to become lowlands, and were strewn with stony detritus, locally reworked and partly stratified by transient streams. Detrital fans near the mouths of shallow gulches merging with the loose stony litter of an arid surface were probably all covered by the tuff and lava of the dacitic eruption and so preserved as the Whitetail formation.

Age.—In the absence of fossils, a rough approximation to the age of the Whitetail formation, deduced from the general physical history of the region, is all that can be offered. As it lay upon the surface over which the probably early Tertiary dacitic lavas were erupted, it also is referred to the same period.

GILA CONGLOMERATE.

General character, thickness, and stratigraphical position.—Gilbert, while studying, in 1873, the region drained by the upper Gila and its tributaries, gave the name Gila conglomerate to certain valley deposits which he describes as follows:

"The bowlders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand, and of trass, and sheets of basalt; the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1,500 feet. They have been seen at so many points by Mr. Howell and myself that their distribution can be given in general terms. Beginning at the mouth of the Bonito, below which point their distinctive characters are lost, they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend 80 miles; on the Prieto, 10; and on the Bonito, 15. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs, and floor the desert plains. Below the Bonito it merges insensibly with the detritus of Pueblo Viejo Desert. It is, indeed, one of the 'Quaternary gravels' of the desert interior, and is distinguished from its family only by the fact that the water courses which cross it are sinking themselves into it and destroying it, instead of adding to its depth."[a]

[a] Wheeler Survey, Vol. III, 1875. Geology, p. 540.

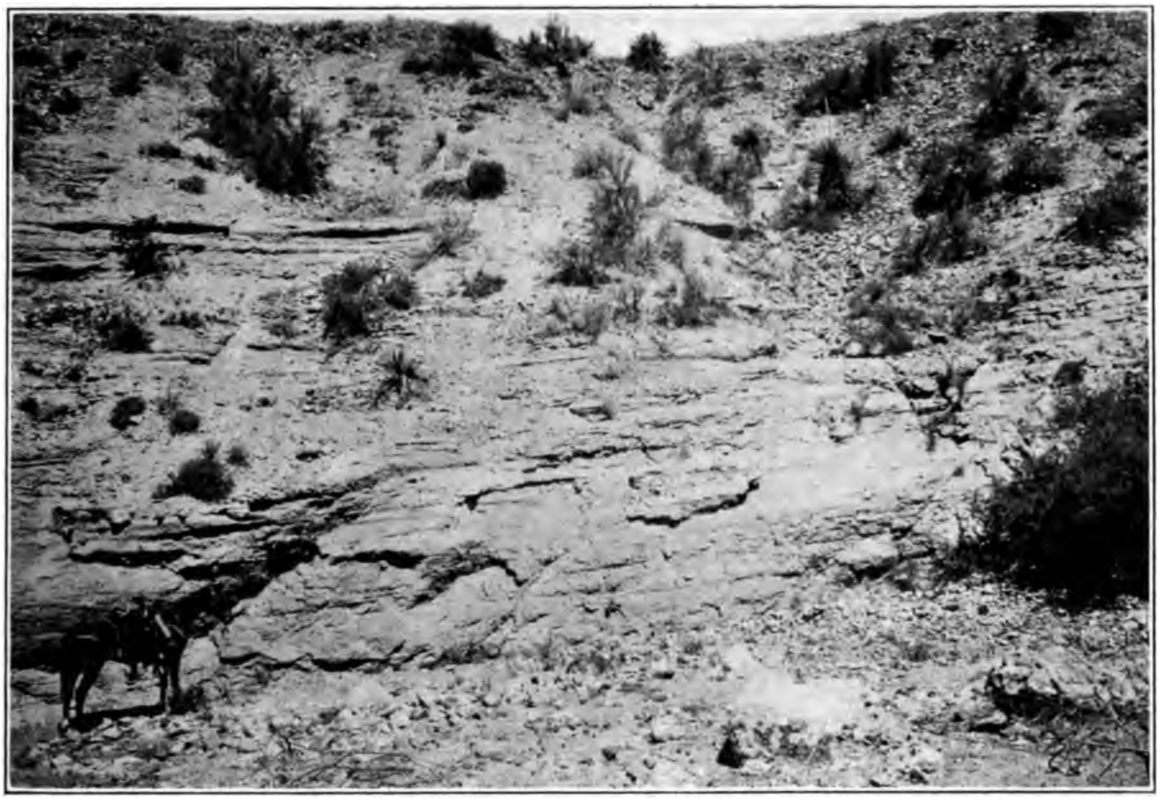
Deposits identical in character and origin, and in part directly continuous with those noted by Gilbert, occur within the Globe quadrangle, and are in this report designated by the same name.

The general character of the Gila formation as it occurs within the Globe quadrangle is that of a firm but not hard conglomerate, the material of which ranges in coarseness from fine sand to bowlders 8 or even 10 feet in diameter. It is nearly always distinctly stratified, but the individual beds show as a rule little persistence, layers of conglomerate passing into sands, or vice versa. (Pl. XII, *A*.) The pebbles are sometimes well rounded, most of them having probably been derived from the erosion of Paleozoic conglomerates, but more often they are subangular or even angular in shape and the formation might appropriately be termed a breccia. The material composing the deposit varies greatly in different portions of the area, as will presently be shown.

The maximum thickness of the Gila conglomerate within the Globe quadrangle is not known. It is certainly more than 700 feet and probably considerably over 1,000 feet. But the bottom of its thickest portions is nowhere exposed. Pinal Creek has not cut down to it, nor has it been reached by any of the wells sunk in the vicinity of Globe.

The Gila formation is essentially a valley deposit, having usually, in spite of deformation and dissection, a still recognizable relation to the larger features of the existing topography. It lies indifferently upon the eroded surfaces of all the other rocks of the quadrangle with the exception of basalt, which occurs as an intercalated flow between the conglomeratic beds, and is therefore of contemporaneous age. The conglomerate is frequently found overlaying dacite, the dacite showing evidence of vigorous erosion prior to the deposition of the conglomerate. This relation is well shown on Mineral Creek, about 1 mile east of the Sixtysix ranch, the conglomeratic beds here abutting obliquely against a crag of dacite, as shown in Pl. XII, *B*.

Distribution.—The largest area of the Gila conglomerate within the bounds of the quadrangle is that which underlies and surrounds the town of Globe, and which may be conveniently referred to as the Pinal Creek area (Pl. VI, *C* and *D*). It occupies the trough between the Apache and Pinal mountains, lapping far up on the flanks of both ranges. On the northeast slopes of the Pinal Mountains the conglomerate attains a maximum elevation of 4,750 feet. On the southwest face of the Apache Mountains it reaches a similar altitude, but being here some miles beyond the quadrangle limits the exact elevation was not ascertained. Near the town of Globe the Gila formation has a width of about 6 miles from southwest to northeast. About 4½ miles northwest of Globe, at the junction of Pinal Creek and Miami Wash, exposures of underlying rock contract



A. CHARACTERISTIC BLUFF OF GILA CONGLOMERATE AS IT OCCURS IN COPPER GULCH NEAR THE TOWN OF GLOBE.

B. BEDS OF GILA CONGLOMERATE ON RIGHT, ABUTTING AGAINST STEEP EROSION SLOPE OF DACTE ON LEFT, 1 MILE EAST OF THE SIXTY-SIX RANCH.

Mineral Creek flows from right to left through a narrow goige in the dacite.

deserves some special description and may form an exception to the foregoing statements. This rock, visible in the bluffs along Pinal Creek from 1 to 2 miles northwest of Globe, in the vicinity of the Old Dominion mine, and in [illegible] and [illegible] the conglomerates in this neighborhood, is locally termed "granite," and several prospecting tunnels have been run [illegible] under the erroneous impression which such a term implies. The material indeed much resembles a rather decomposed crumbling granite. But closer examination shows that it is a detrital deposit in which bowlders or fragments, up to [illegible] in diameter, of a gray quartz-mica-diorite, of the same petrographical character as that occurring in the schists of the Pinal Mountains, are embedded in finer detritus of the same material. (See Pl. XIII, A.) The general decomposition of the whole and its crumbling character tend to obscure the clastic nature of the deposit. The maximum thickness of this accumulation of diorite material is not known. It grades upward by gradual admixture of limestone and other pebbles into the usual Gila conglomerate of the Pinal Creek area. Natural sections in the ravine north of the Old Dominion mine and underground workings show that the bed of quartz-mica-diorite detritus rests upon the surface of a flow of [illegible], and that this contact dips at a considerable angle toward Pinal Creek. (See [illegible].)

[illegible] associated with the dioritic conglomerate is a facies (variety) of the Gila conglomerate made up of fragments of a somewhat decomposed yellowish granite-porphyry, which might also be easily mistaken for a mass of shattered rock practically in place. Its geological position, however, determines it beyond doubt as a part of the Gila formation. It is best seen where cut by the new [illegible] of the Old Dominion mine. No good natural exposures are known, outcrops of the material being concealed by numerous loose fragments of the porphyry which cover the ground between the rock breaker and [illegible] of the Old Dominion mine.

Overlying the basal deposit of diorite bowlders and fragments in the vicinity [illegible] are the ordinarily bedded conglomerates and sands which form the hills and [illegible] about the town. These contain much granitic detritus in the [illegible], which, however, is less abundant in the upper strata. The generally [illegible] pebbles of [illegible] quartzite, limestone, diabase, or granite, which make up the [illegible] part of the deposit are usually less than 6 inches in diameter. Excellent sections of these conglomerates have been provided through the [illegible] of the present streams, and the deposit can be well studied along the [illegible] of Pinal Creek, in the lower part of Copper Gulch, in Russell Gulch, and [illegible] Flat.

[illegible] the conglomerates [illegible] toward the Pinal Moun-

A. COARSE CRUMBLING QUARTZ-DIORITE DETRITUS, FORMING BASAL PORTION OF GILA CONGLOMERATE NEAR GLOBE.

Exposure is in Copper Gulch. In the upper right-hand corner of the picture the material passes into a more common facies of the conglomerate, showing imperfect stratification.

B. COARSE BRECCIA OF DACITE AND SCHIST, FORMING PART OF THE GILA CONGLOMERATE NEAR THE HEAD OF WEBSTER GULCH.

tains, whence they were derived, they become notably coarser, and close to the range contain angular blocks of quartz-mica-diorite, granite, and schist up to 5 or 6 feet in diameter. The deposit as a rule is less distinctly bedded near the mountains than at a distance of a few miles away.

The Mineral Creek area of the Gila conglomerate differs rather strikingly in the nature of its materials from the Pinal Creek area. Excellent exposures of the formation are visible on Lyons Fork of Mineral Creek, where the basal bed, resting on dacite, is made up of angular blocks of the latter rock of all sizes up to 2 or 3 feet in longest dimension, embedded in an abundant pinkish matrix which is made up of sandy dacitic detritus. A few feet above the base, fragments of schist may be observed mingled with those of dacite, and still higher in the series the schist predominates over the volcanic rock. The whole of this basal portion of the deposit shows so little rounding of the rock fragments as to be, strictly speaking, a breccia rather than a conglomerate. This breccia is overlain by a series of locally very regularly stratified, light-colored, tuffaceous beds, alternating with beds of conglomerate. The tuffaceous beds are made up very largely of sherds of vesicular or pumiceous volcanic glass, and some of the nearly white beds contain, except occasional particles of quartz and feldspar, scarcely any other material. Other beds show numerous fragments of dacite, quartzite, and schist, while still others are composed wholly of such subangular rock fragments, and resemble the more usual type of the Gila conglomerate found in the Pinal Creek area. On Lyons Fork the tuff and conglomerate beds strike north 65° east, and dip southeasterly at an angle of about 30°, but rather abrupt changes in dip are not uncommon. Between the junction of Lyons Fork with the Dry Wash of Mineral Creek and the Sixtysix ranch the Gila formation is well exposed in the bluffs along the east side of the arroyo. Here it is composed of angular fragments of dacite, schist, diabase, and limestone, the blocks being sometimes 2 or 3 feet across, embedded in a finer conglomeratic or sandy matrix composed of the same materials. The larger angular blocks are not mingled indiscriminately with the finer material, but tend to occur most abundantly along certain rude stratigraphical planes within the mass.

Along Mineral Creek east of the Sixtysix ranch and in the arroyos north of Government Spring the Gila conglomerates and intercalated tuffaceous strata occur in thick beds which are excellently exposed in the stream bluffs. The fragments of the conglomerate vary greatly in size, ranging from fine sand up to subangular or angular blocks 3 feet in diameter, composed of schist, quartzite, limestone, or dacite.

About a mile east of Government Spring the tuffaceous beds disappear and the visible portion of the Gila conglomerate is made up chiefly of fragments of schist and quartz-mica-diorite from the Pinal Range. The beds here dip gently away from the mountains toward the southwest.

The Gila formation of the upper Pinto Creek area is exceedingly variable in character and is noteworthy as containing an intercalated flow of basalt, which is described on pages 95 to 97. The southern portion of this area, which, as already indicated, is nearly surrounded by the Schultze granite, is characterized by a conglomerate composed almost wholly of granite, with a small proportion of schist and quartz fragments. The granitic fragments or bowlders are of all sizes up to 6 or even 10 feet in diameter, and are embedded in a matrix of granitic detritus. The granite of these blocks is identical in character with that which forms the adjacent hills, and one looking over the region from any of the neighboring summits and noting the uniform color and obviously granitic character of the rocky surface might readily suppose all to be granite in place. But on closer scrutiny the eye detects the more rounded contours of the hills carved from the Gila conglomerate and the absence of the occasional projecting crags which characterize the true granite topography, while the occurrence of occasional blocks of schist shows that the crumbling granitic detritus which covers the surface has been derived not from an underlying granite in place, but from a remarkably coarse granite conglomerate containing scattered schist bowlders.

Toward the northwest the material of the Gila conglomerate changes rather rapidly, the granitic bowlders and matrix giving place to dacitic detritus. Underlying the flow of basalt just north of Cottonwood Canyon and resting upon granite and schists is a soft, well-bedded pinkish deposit made up of small angular particles of schist and quartz with larger fragments of dacite, all embedded in a dacitic matrix which gives the general color to the deposit. This matrix was at one time a mud or silt made up of fine detritus washed from slopes of dacite in the vicinity. The thickness of the deposit where exposed on Cottonwood Arroyo is about 30 feet, but it is merely the thin edge of a formation elsewhere much thicker.

North of the road connecting Pinto Creek with Webster Gulch the Gila formation becomes in places very coarse, bowlders of dacite up to 5 feet in diameter occurring embedded in a matrix of finer dacitic detritus. These very large bowlders are apparently of local distribution, the bulk of the formation consisting of smaller fragments.

In the lower part of Gold Gulch, near the edge of the quadrangle, is a mass of the Gila conglomerate which, while lying in the general line of the elongated area just described, is not directly connected with the latter. It is nearly surrounded by slopes of dacite, and consists almost exclusively of detritus of this rock. The only foreign material noted was a single bowlder of diabase. The fragments of dacite comprising this remarkable deposit range in size from those having a diameter of 10 feet down to particles of microscopical dimensions. The larger fragments are embedded in an abundant matrix of the finer material, the whole having a prevailing pinkish color. The conglomerate is distinctly bedded, the beds dipping toward the axis of the little valley in which they lie, at angles up to 30°. The deposit rests directly upon massive dacite, and has a maximum thickness of something over 75 feet.

In the Needle Mountain area the most interesting exposures of the Gila formation are found along the Pinto Creek road and on the summit of Needle Mountain. Along the road just mentioned the deposit is made up of more or less angular fragments of dacite up to 6 feet in greatest diameter embedded in a firm, tough matrix, consisting chiefly of dacitic particles, but containing also many fragments of schist and some of quartz. This matrix is now sufficiently hard to form waterworn bowlders in the bed of the present arroyo. A typical exposure of this breccia or conglomerate is shown in Pl. XIII, *B*, from a photograph taken by the roadside about three-quarters of a mile west of the branch to the Continental mine. The fragments over 6 inches in diameter are chiefly dacite. As shown by the illustration, the material lies in rude nearly horizontal beds.

From the Pinto Creek road southward to Needle Mountain there intervenes a distance of about a mile, within which the Gila formation undergoes striking change. The dacitic bowlders disappear to the south and are replaced by fragments of schist and of granite derived from the Schultze ranch area. The matrix continues to resemble that just described, but the place of the finer schist particles is taken by bits of granitic quartz and feldspar.

The craggy summit of Needle Mountain is composed of Gila conglomerate, or breccia, as this facies might more properly be called, which has been carved by erosion into the pinnacles whence the mountain derives its name. The general appearance of this breccia is shown in Pl. XIV, *A*, from a photograph taken on the summit of the peak. The large, more or less angular fragments shown in the illustration are mostly blocks of granite varying in size up to 5 feet, with a smaller number of schist fragments. The matrix by which these masses are firmly held together is composed of fine granitic detritus, the particles being coated and cemented with oxide of iron, which gives it a pale brick-red color, while the large granite bowlders, derived from the neighboring area of light-colored granite, are nearly white. The result is a rock of unusually striking appearance.

Immediately east of Needle Mountain the Gila formation becomes almost exclusively granitic, although there is occasionally some dacitic material in the matrix. This matrix, however, is rarely seen, as the ridges are covered with the large granitic bowlders which have weathered out from the conglomerate. The result is a surface thickly strewn with masses of fairly fresh granite, and closely resembling that of a moraine. It is moreover sometimes difficult to believe that there is not granite in place immediately beneath so granitic a cover.

The bowlders of the Gila formation rapidly diminish in size to the east of Needle Mountain. At a distance of a mile they are no larger than is common in the beds between Miami Flat and Globe, and consist chiefly of quartz, quartzite, and schist, pebbles or fragments over 2 inches in diameter being rather rare. Such material is less resistant than that capping Needle Mountain, and forms the rounded gravel-strewn hills characteristic of the Gila formation.

The lower Pinto Creek area of Gila conglomerate extending generally eastward from Horrell's west ranch on Pinto Creek is in part made up of reddish beds composed chiefly of pebbles of dacite with some of quartz, quartzite, and diabase, firmly held in a partly dacitic matrix. These conglomerates are not conspicuously coarse.

Much more might be written descriptive of the Gila formation, so variable is it from point to point. But enough has been presented to give some idea of the nature and extent of the characteristic changes of material dependent upon very local circumstances.

Relation to early topography.—As pointed out by Gilbert,[a] the Gila formation is essentially a valley deposit. Although its occurrence is not at the present time confined to existing valleys, it is plain that it originally accumulated in depressions or lowlands separating mountain ridges, and never formed a continuous deposit over the whole region. Throughout the period of its deposition the Pinal Mountains must have existed as a high range, and the vigorous erosive sculpturing of their slopes contributed a large share of the conglomeratic material.

The conglomerate and tuff of the Mineral Creek area appear to have been laid down in a valley bounded on the east by the main Pinal Range and on the west by extensive slopes of dacite, upon which it undoubtedly overlapped to an unknown distance to the west. The occurrence of patches of the conglomerate at an elevation of 5,400 feet just east of Hutton Peak indicates that the Mineral Creek deposit was once much more extensive, and that its boundaries could not have been embraced within the limits of the present valley, upon the floor of which the remnant of the formation lies. The conglomerate originally either swept round to the north past the position of Pinal ranch and joined the upper Pinto Creek area, or else there existed in the vicinity of the ranch a dividing ridge which has since been reduced by erosion. The latter hypothesis is considered most probable and most accordant with what has been observed elsewhere in the district. No evidence has been discovered to indicate that the conglomerates near Hutton Peak owe their relatively high elevation to faulting.

[a] Wheeler Survey, Vol. III, 1875, Geology, p. 540.

The Apache Mountains, northeast of the quadrangle, must also have existed although their structure has probably undergone modifications since the conglomerate was deposited. In the valley between the Pinal and Apache mountains was laid down the largest single area of conglomerate within the quadrangle.

Over most of the northern half of the quadrangle, however, the relation of the Gila formation to an older topography is less clearly read. As the deposit forms the summit of Needle Mountain there is at present no topographical barrier between the Needle Mountain and upper Pinto Creek areas. But the coarse nature of the conglomerate on the peak indicates that it was deposited close to a mountain slope, and the character of its materials points plainly to their derivation from the west or southwest. The occurrence of the deposit on the summit of a peak which dominates the surrounding country within a radius of 3 miles is alone eloquent of erosion, and taken in connection with the character of the material in the conglomerates of the Needle Mountain and upper Pinto Creek areas, indicates that the two were formerly separated by a northwest-southeast ridge forming a continuation of the Pinal Range. The Needle Mountain area of conglomerate appears to have been deposited on the north against the thick accumulation of dacite which now culminates in Webster Mountain, and which undoubtedly supplied most of the dacitic detritus to the younger formation.

The lower Pinto Creek area, while obviously modified in outline by deformation and erosion, lies within a valley which in general still persists as part of the drainage basin of Pinto Creek.

The presence of several small patches of the Gila conglomerate northeast of Webster Mountain indicates the former existence of a valley in which the gravels were laid down. But subsequent deformation and erosion have obliterated the boundaries of this hollow.

In the northeast corner of the quadrangle the deposits of Gila conglomerate are in general related to the present valleys. They consist chiefly of quartzite, and grade without any discoverable break into the modern talus from the quartzite ridges.

The relation thus sketched between the Gila formation and the earlier and the present topographies may be summed up in a general statement. An observer standing on a commanding elevation, such as Pinal Peak, will see below him to the northeast the broad basin in which the town of Globe lies, evidently deeply filled with a relatively soft deposit, intricately carved by the present system of arroyos. (Pl. III, *B*, and Pl. VI, *C* and *D*.) He will observe that the deposit is not horizontal, but slopes gently up to the foot of the range upon which he stands, and up to the Apache Mountains to the northeast. He will see that it is continuous, with much larger areas to the southwest, apparently filling the basin of the Gila and extending up in long terraced slopes to the Pinaleno and other ranges. The impression made by such a broad view (see Pl. VI, *C* and *D*) is that the conglomerate merely fills the existing valleys, and is now being trenched by the streams as a consequence of simple regional uplift or climatic changes. But detailed study of the district soon modifies this first impression, and it becomes evident that both deformation and erosion have locally effected topographical transformations whereby valley bottoms of the time of deposition of the Gila formation have in some cases become mountain tops of to-day.

Origin.—The rapid variation in character, the coarseness and angularity of the bowlders, the distribution of the material with reference to existing mountain ranges, the nature and dip of the stratification, and the frequent abrupt changes observable in both horizontal and vertical sections, all point decisively to the result of fluviatile action. The bulk of the Gila formation, as it occurs in the Globe quadrangle, was deposited by streams, and resembles the material found in the beds of the prevailingly dry arroyos to-day.

The freshness of the material forming the pebbles and bowlders, taken in connection with their angular shape, indicates that the detritus supplied to these streams came from slopes where mechanical disintegration strongly preponderated over rock decay—a characteristic of the region at the present time. The occurrence of large angular blocks near the mountains with the rapid gradation into finer materials toward the middle of the depositional tract, point to tumultuous transportation—to torrential rushes of water by which large quantities of rock waste were transported in a short time from the mountain slopes to the valley with little of that rounding of individual fragments which characterizes the action of streams having a more constant flow, and in which the materials as a rule travel more leisurely to greater distances before coming to rest. As already pointed out under the heading "Climate," the present erosion in this arid region shows similar charateristics—turbulent floods of water roaring suddenly down channels whose dry beds have been exposed for months to the burning rays of the sun. The transporting power of the streams which deposited the Gila formation diminished very rapidly after they issued from the mountain canyons, and their load was deposited over the valley floors as a series of coalescent detrital fans.

That the conditions of deposition just outlined were not unfavorable to the occurrence of associated lake deposits in the middle of the larger valleys is certain, and it would not be surprising to find in some of the larger basins outside of the Globe quadrangle fluviatile deposits passing into lacustrine sediments. Such a condition seems to have obtained in the Tonto Basin, north of the region here discussed. But even in smaller valleys it is probable that the in the form of sills, dikes, and irregular masses. In order to avoid the reiteration of technical petrographic terms, which mean little to most readers, the various granitic rocks will usually be referred to by local names, such as Madera diorite, or Schultze granite, consisting of a geographical term denoting a place of characteristic occurrence and a general rock name as simple and familiar as possible.

MADERA DIORITE (QUARTZ-MICA-DIORITE).

Definition.—Quartz-mica-diorite is usually a gray rock of granitic texture and habit, consisting essentially of plagioclase feldspar (usually andesine) with quartz and black mica (biotite). There is sometimes a little orthoclase or microcline present, in which case the rock approaches granodiorite in composition, while by the addition of hornblende it may grade into tonalite. The local name Madera diorite is derived from Mount Madera, one of the peaks of the Pinal Range.

Occurrence and distribution.—Under the name quartz-mica-diorite may be included a large part of the granular plutonic rocks intrusive as batholiths into the Pinal schists and locally known as "granite." This rock closely resembles many true granites in its general texture, prevailing gray color, and mode of weathering. Close inspection, however, reveals the fact that the dominant feldspathic constituent is plagioclase and not, as in granite proper, orthoclase.

As may be seen from the map, the Madera diorite, with the exception of a single small mass in schist, north of Black Peak, is limited in its distribution to the southern half of the quadrangle, where it forms exceedingly irregular bodies which have extensively invaded the schists, dividing the latter into detached masses of widely variant shapes and sizes. The relation of the quartz-mica-diorite to the schists is often exceedingly intimate. Irregular tongues of the intrusive rock extend into the schists, and fragments of the latter are often thickly crowded as inclusions in the former.

For convenience of description the Madera diorite may be treated in four areas. The first of these, which will be called the Crest area, is the most northerly. Its name is suggested by the fact that it occupies much of the crest of the Pinal Mountains (including Mount Madera), from the Ridge road, in Russell Gulch, northward to the trail between Globe and the Hog ranch. On the west it forms the ear-shaped area extending southward from the above named ranch across Lyons Fork of Mineral Creek. On the east it is the principal rock of Russell Gulch, up which the Ridge road passes, and extends down beneath the conglomeratic beds of the Gila formation. As far as existing exposures go, the Crest area of quartz-mica-diorite is distinct from other areas of similar rock to the southeast. This isolation, however, is undoubtedly more apparent than real. Connections probably exist beneath the covering of Gila conglomerate and beneath the schist masses at the head of Icehouse Canyon.

The second area lies east of the Crest area and is of comparatively small extent. It comprises the rock in which Icehouse Canyon is excavated and extends eastward across Pinal Creek, where it is united by a narrow ribbon of the diorite between two schist areas with the third and much larger and very irregular mass forming Pinal Peak area, so called from the mountain of that name. It is the quartz-mica-diorite of the Pinal Peak area, often thickly crowded with schist inclusions, which is so well exposed along the stage road that, crossing the range at the head of Pinal Canyon, connects Globe with Florence.

The last and fourth area lies in the extreme southeastern corner of the quadrangle, and may be conveniently referred to as the Southeastern area. It probably connects with the Pinal Peak mass to the northeast, beyond the bounds of the quadrangle.

Although all four areas are extremely irregular in outline, they yet, as may be seen on the geological map (Pl. I), show a tendency to elongation parallel with the general strike of the schists, which is northeasterly and southwesterly.

Petrography.—The characteristic rock of the Crest area is granitic in general aspect, usually massive, but it becomes somewhat gneissoidal near the contact with the Pinal schists, particularly to the east of the Hog ranch. Its usual color is bright gray, with none of the flesh-colored tint commonly associated in this region with rocks containing much orthoclase. Epidote is sometimes locally abundant as greenish-yellow flecks, streaks, and veinlets, particularly near the contact with other rocks. The rock is not porphyritic, but has a uniform granular texture, the average size of the component mineral grains being somewhat less than 5 millimeters. The minerals visible to the unaided eye are milky-white feldspar, usually showing albite striations, quartz, and abundant black mica.

The structure as seen under the microscope is typically hypidiomorphic granular, the plagioclase and biotite usually having partial crystallographic outlines. The principal constituents in order of apparent abundance are plagioclase, which optical tests indicate to be labradorite of the approximate composition $Ab_1\ An_1$[a], quartz, biotite, microcline or orthoclase, and muscovite. The accessory constituents are iron ore, apatite, titanite, rutile, and zircon. Epidote and a little sericite and chlorite are always present as secondary minerals. Hornblende is not a constituent of the typical rock of the area, but may occur abundantly in certain contact facies, to be presently described.

The amount of orthoclase or microcline present is subject to considerable variation, and, as in the granodiorites and quartz-diorites of the Sierra Nevada,

[a] The method of Michel Lévy, in connection with that of Becke, has been used throughout this investigation for the determination of the feldspars.

is perfectly allotriomorphic and often incloses the more nearly idiomorphic plagioclase. The orthoclase is sometimes partly sericitized, but the microcline is fresh and clear. Both forms probably contain a small proportion of the albite molecule, as indicated by occasional departures from optical homogeneity.

A chemical analysis of an apparently representative specimen collected 2 miles south of the Hog ranch is given under I, while under II is placed an analysis of a typical granodiorite for comparison.

Chemical analyses of quartz-mica-diorite and granodiorite.

[Dr. W. F. Hillebrand, analyst.]

	I.	II.	III.
SiO_2	61.99	63.85	58.74
Al_2O_3	15.81	15.84	16.02
Fe_2O_3	3.28	1.91	4.16
FeO	2.69	2.75	3.50
MgO	2.24	2.07	2.18
CaO	4.62	4.76	5.12
Na_2O	2.73	3.29	3.26
K_2O	2.51	3.08	2.39
H_2O-	.91	.28	.83
H_2O+	1.99	1.65	1.60
TiO_2	.94	.58	1.29
ZrO_2	.03	....	.05
CO_2	None.	....	None.
P_2O_5	.11	.13	.56
Cl	Undet.	....	Undet.
F	Undet.	....	Undet.
S	Trace.	....	[a](.06)
Cr_2O_3	Trace.	....	....
NiO	Undet.	....	Trace (?)
MnO	Trace.	.07	.22
BaO	.06	.06	.10
SrO	Undet.	Trace.	Trace.
Li_2O	Undet.	Trace.	Trace.
FeS_2	....	....	11
Total	99.91	100.32	100.13

[a] Calculated as FeS_2.

I. Quartz-mica-diorite, 2 miles south of the Hog ranch, Globe quadrangle, Arizona.

II. Granodiorite, Grass Valley, Nevada County, Cal. Lindgren, Am. Jour. Sci., 4th series, Vol. IX, 1900, p. 273, analysis III.

III. Quartz-mica-diorite, Florence stage road, 2 miles south of Pinal Peak.

diorites rather than with the granodiorites, in which the potassium feldspar should amount to at least 8 per cent. Microscopical examination of thin sections shows, however, that in the particular specimen analyzed the proportion of this feldspar is below the average for the area as a whole. Although the amount of calcium is about the same in the two rocks, in the Grass Valley granodiorite it is partly combined in the hornblende molecule, while in the Madera diorite, where biotite plays the rôle of dark constituent, the calcium, with the exception of a very little in the biotite, titanite, and apatite, is apparently all combined with sodium to form labradorite, an abnormally calcic feldspar for typical granodiorite, for which the characteristic plagioclase is oligoclase or andesine. The biotite also, by levying on the supply of potassium, reduces the amount available to form potassium feldspar.

The comparison of the chemical and mineralogical compositions of the two rocks furnishes an interesting example of the crystallization of chemically similar magmas into mineralogically diverse aggregates.

Although microscopical study shows that orthoclase or microcline are sometimes more abundant than in the rock selected for analysis, it nevertheless seems advisable to adopt the name quartz-mica-diorite for the mass as a whole, recognizing that it closely approaches the granodiorites and occasionally shows granodioritic facies.

The Crest area of the Madera diorite is not bordered by any persistent peripheral facies, but a well-marked differentiation into local contact modifications occurs at a few points, particularly in the vicinity of the saddle through which the trail from Globe to the Hog ranch passes, and near the contacts with the inclosed masses of schist on the eastern slope of the Pinal Range. These facies are darker in color than the normal rock, and evidently contain hornblende as well as biotite, while the quartz becomes very inconspicuous. Under the microscope these darker rocks show a hypidiomorphic granular structure and consist of plagioclase, quartz, hornblende, and biotite, with accessory iron ore, apatite, titanite, and zircon. The plagioclase is labradorite, ranging from Ab_3An_4 to somewhat more calcic varieties. The quartz is wholly allotriomorphic, with a tendency to become interstitial. Potassium feldspars were not noted in the thin sections examined, but probably occur in transitional facies. The hornblende is the common variety, greenish yellow by transmitted light, usually found in dioritic rocks, and the biotite presents no noteworthy features. The secondary minerals are chlorite, largely after biotite, and epidote. The rock is a quartz-hornblende-biotite-diorite, differing from the main rock of the area in the presence of abundant hornblende and in its more calcic feldspars.

The rock of Icehouse Canyon is gray in tint, of rather evenly granular as to leave no doubt but that both rocks solidified from the same magma, and in all probability they represent one general period of intrusion.

Two miles nearly due east of Pinal Peak a specimen was collected from the crest of the ridge lying east of the stage road, which shows abundant small phenocrysts of potassium feldspar. Under the microscope these phenocrysts prove to be microperthitic microcline, which is apparently quite as abundant as the labradorite or andesine plagioclase present. Among the accessory minerals titanite, often in sharply idiomorphic crystals, is more abundant than in the quartz-mica-diorite typical of the area. This exceptional rock is perhaps a monzonitic facies of the quartz-diorite, as it apparently did not form a distinct area. Its relation to the prevalent rock was, however, not clearly established.

The red color of the Madera diorite where it is overlain by the Apache group is the result of the pre-Cambrian weathering of the old surface upon which the sediments were laid down. The immediate cause of the coloration is the decomposition of the feldspars which the microscope shows to consist of fine kaolinitic aggregates containing minute dust-like particles of iron oxide.

The granitoid rock of the Southeastern area is probably continuous to the east, beyond the edge of the quadrangle, with the quartz-mica-diorite of the Pinal Peak area. It varies in color from gray near the eastern border of the area to red where it underlies the Apache group to the west. It crumbles readily when weathered, and exposures of firm fresh rock are not abundant. Specimens of the latter show a handsome greenish-gray rather coarsely crystalline rock, in which occur scattered and irregular phenocrysts of pink potassium feldspar up to 2 or 3 centimeters in length. The constituents making up the granular groundmass have an average diameter of about 5 millimeters and comprise a rather oily green plagioclase, quartz, and biotite.

A thin section under the microscope shows a hypidiomorphic granular aggregate of plagioclase, quartz, microcline, and biotite, named in order of apparent abundance. The plagioclase is principally andesine. The microcline occurs as the porphyritic crystals noticeable in hand specimens and as irregular inclusions in the andesine.

The accessory and secondary minerals are those already noted for the Pinal Peak area.

This rock has not been subjected to chemical analysis, but the microscopical examination indicates that although potassium feldspars are scarcely so abundant as the conspicuous phenocrysts might suggest, it is probably more nearly a granodiorite than the quartz-mica-diorites described in the preceding pages. In the absence of chemical investigation, however, and in consideration of its probable continuity with the plutonic mass of Pinal Peak, the rock is provisionally included with the Madera diorite.

The existence of a very small mass of quartz-mica-diorite north of Black Peak was referred to on page 58. This is a dark-gray gneiss, which has apparently been subjected to some of the same squeezing that has metamorphosed the surrounding schists, into which it was originally intruded. It consists of plagioclase, largely sericitized, quartz, biotite, and a little green hornblende, with the usual accessory and secondary minerals. The quartz is thoroughly granulated and the granules arranged in bands. Although more metamorphosed than the quartz-mica-diorite of the larger masses in the Pinal Range, the rock of this little area was probably of the same general type originally and belonged to the same period of intrusion. It is accordingly mapped as Madera diorite.

SOLITUDE GRANITE (GRANITE AND MUSCOVITE-GRANITE).

Definition.—The term granite, used strictly and without modification, stands for a granular plutonic rock, consisting essentially of a potassium feldspar (orthoclase or microcline) quartz, muscovite, and biotite. If the black mica is absent entirely, the rock is termed muscovite-granite. There is usually present also a subordinate amount of plagioclase—either albite or oligoclase.

Occurrence and distribution.—Granite (using the word in its strict petrographical sense) and muscovite-granite are not abundant rocks in the Globe quadrangle. Their occurrence is limited as far as known to three small areas. One of these lies half-way between Black Warrior and the Continental mine, and may be called the Willow Spring area from the gulch of that name. It will be described later under the heading "The Willow Spring granite." The other two lie southeast of Bloody Tanks, at the head of Solitude Gulch, and together cover about 3 square miles. The latter are masses of very unequal size, separated by a narrow strip of schist. The rocks of these two areas, while in part of similar mineralogical composition, are different in appearance and texture, and will be separately described. They, like the other granitic rocks of the Pinal Range, are intrusive into the Pinal schists. The smaller of the two southerly masses is cut by porphyry dikes sent out from the Schultze granite.

Petrography.—The principal rock of the southern and largest mass is a light gray, sometimes nearly white muscovite-granite, passing with no recognized break into true granite in the southern portion of the area. It weathers in yellowish tints, resembling in this respect the granitite of the Schultze area, rather than the grayish-weathering quartz-mica-diorites of the southern part of the Pinal Range. It is massive, and usually of evenly granular texture, the average size of the grains being about 5 millimeters. The minerals visible to the naked eye are quartz, porcelain-white feldspar, silvery white mica (muscovite), and sometimes black mica (biotite).

Under the microscope the rock shows a nearly allotriomorphic aggregate of quartz, microcline, and orthoclase in varying proportions, albite or oligoclase, and muscovite. Although the biotite is often entirely lacking, in some facies it is nearly as abundant as muscovite, and the rock becomes granite proper. On the whole, microcline, quartz, and muscovite are the most constant and important constituents, and dark minerals are notably lacking. The feldspars, although somewhat turbid with dust-like particles, are generally fresh. Intergrowths of the various feldspars are common. The quartz grains, as seen in thin section, usually consist of several interlocking granules, but this structure is apparently not of cataclastic origin.

Accessory minerals are always very sparingly present. They are titanite, zircon, and tourmaline, the latter in minute prisms. The rock as a whole may be described as a muscovite-granite with true granitic facies.

The rock of the neighboring smaller area is darker in color and finer grained. In fresh exposures it always shows a peculiar streaky appearance, suggestive of imperfect mixing of a heterogeneous magma.

Hand specimens show a uniformly fine granular texture, the muscovite and biotite, the latter sometimes aggregated to little dots or bunches, being the only minerals easily recognized by the unaided eye.

Under the microscope, quartz, muscovite, a little albite or oligoclase, and occasionally andalusite appear as allotriomorphic grains, either intricately interlocking or poikilitically inclosed in a somewhat indistinct matrix or mesostasis which is principally if not wholly orthoclase. The andalusite is always allotriomorphic and usually closely associated with the quartz and muscovite. It shows the cleavage, faint green and pink pleochroism, index of refraction, double refraction, and other optical properties characteristic of andalusite, but is free from the black carbonaceous inclusions common in this mineral when a constituent of contact metamorphic rocks.

Andalusite has been described by Teall[a] as a constituent of granite in Cornwall, where it is associated with sillimanite and possibly cordierite, and by Cohen[b] in granites of the Schwarzwald and Vosges Mountains.

Although in the Arizona occurrences the mineral has apparently as much title to primary origin as the quartz, muscovite, and feldspar, the general microstructure of the rock admits, if it does not suggest, extensive recrystallization brought about by metamorphic action, such as might be ascribed to the intrusion of the later granitite of the Bloody Tanks area. The well-known association of andalusite with contact metamorphism imposes the burden of proof upon any apparent occurrence of it as a primary constituent of an eruptive rock. In the present instance the proof is not at hand.

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[a] Mineralogical Magazine, Vol. VII, 1887, pp. 161-163.

[b] Neues Jahrb. f. Min., 1887, Vol. II, pp. 178-180.

The purely accessory minerals of this granite are apatite, titanite, zircon, and iron ore, none of them being abundant.

The secondary minerals are a little chlorite and epidote.

SCHULTZE GRANITE (GRANITITE OR BIOTITE-GRANITE).

Definition.—Biotite-granite or granitite is a granular plutonic rock, consisting normally of orthoclase, quartz, and biotite, with usually a little oligoclase. The rocks presently to be described depart rather widely from the type and furnish an interesting illustration of the unsatisfactory and transitory character of the general scheme of rock classification now in use.

Occurrence and distribution.—In contradistinction to the quartz-mica-diorite, which occupies the southern third of the quadrangle, the characteristic granitoid rocks of the northern two-thirds of the region are granitites. In order to bring out certain slight mineralogical differences, possibly indicative of difference in age, these granitites, occurring in many separated areas, are mapped and described in two geographical groups, namely, the Schultze granite, so called from the Schultze ranch, and the Ruin granite, from Ruin Basin, a name given to this hollow on account of unusually abundant ruins of prehistoric villages that dot its floor.

The largest and most interesting mass of Schultze granite forms what may be termed the Bloody Tanks area, which from the Pinal ranch on the west stretches eastward across Pinto Creek to Liveoak Gulch. It is this rock which forms the light-colored hills about Schultze's ranch and the rather conspicuous white peaks east of the Pinal ranch. As a rule its erosion tends toward the development of broad basins and moderate slopes, which, however, are often hilly and may be exceedingly rough in detail. The surfaces of these hills are but poorly screened by scanty vegetation, so that the rounded outcrops of granitic rock and the smoother slopes covered by loose particles of feldspar, quartz, and mica impart a pale-yellow tone to the landscape.

A rather conspicuous jointing is characteristic of the mass and is particularly well developed along Pinto Creek (Pl. VIII, *B* and Pl. XIV, *B*), where the granite is regularly divided into great slabs by joints which strike about north 65° east and dip southeasterly at about 60°. Joints having this general trend are abundant over most of the Bloody Tanks area, but they are often associated with northwesterly joints and with still others running in various directions.

Marvine, whose route in 1871 evidently led him across the Pinal Range by way of Bloody Tanks and what is now Schultze's ranch, gives a general description of the Schultze granite. He says: "The granite is a handsome coarse granular aggregate of quartz grains and orthoclase, large projecting crystals of the latter, which is mostly white, mottling the weathering rock, while the mica is subordinate, occurring in small black flakes. It is characteristically cut in deep and rugged ravines, and is at first strongly affected with joints having a southern trend and inclined 65° to 80° eastward, with a subordinate system of east and west joints dipping north, the two together tending to stud the surface with large tombstone-like slabs of rock. The first set of joints swings westward as the range is crossed." [a]

The portion of the granitic area lying north of Bloody Tanks and drained through Liveoak Gulch is characterized by a porphyritic facies which has been much fissured and altered, and is often conspicuously stained with salts of copper.

The Bloody Tanks mass of biotite-granite is nowhere in contact with the Paleozoic sediments of the region, so that its age relative to these is not directly determinable.

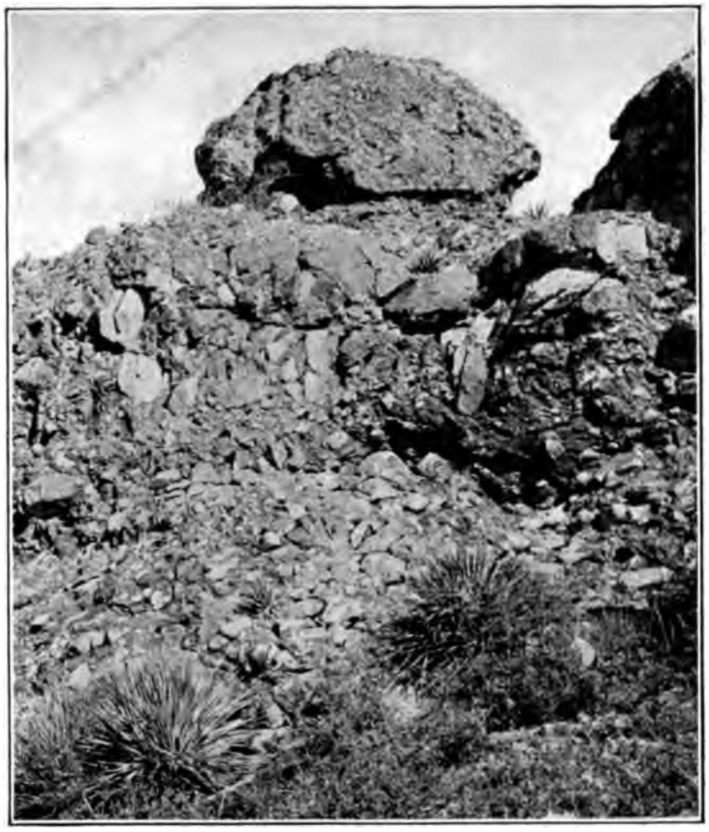
Another mass of granitite, which is correlated with the Schultze granite, lies to the west of the Continental mine, and may be conveniently referred to as the Porphyry Mountain area, since it forms the mass of Porphyry Mountain. North of the mine the granitite has the reddish color which is always associated with the pre-Cambrian erosion surface, and is overlain by the basal conglomerate and some of the lower quartzites of the Apache group.

Petrography.—The granitoid rock of the Bloody Tanks area is characterized by a prevalent porphyritic structure and a generally light tint. The usual color of slightly weathered surfaces is pale yellow, but fresh specimens are nearly white, speckled with small flakes of black mica. The constituents visible to the unaided eye are porphyritic crystals of a fresh, white feldspar often as much as 2 inches in length, showing the brilliant cleavage faces and carlsbad twinning characteristic of orthoclase. These phenocrysts lie in a medium granular groundmass whose constituent grains vary from 1 or 2 millimeters up to a centimeter in diameter and comprise quartz, white feldspar, and biotite. Close inspection of cleavage faces shows that the feldspar of the groundmass is predominantly plagioclase. Such is the rock in which the kettle-like holes are eroded at Bloody Tanks, and which is well exposed around the Schultze ranch, on Pinto Creek, and along the trail from this creek to the Pinal ranch.

Under the microscope thin sections (which as a rule illustrate chiefly the groundmass or granular portion of the rock) show a hypidiomorphic granular aggregate of oligoclase, quartz, orthoclase, and biotite, with accessory muscovite and a very little iron ore, apatite, and zircon. Small amounts of epidote and chlorite are occasionally present as alteration products of biotite.

The oligoclase, although containing a little brownish microscopic dust, is generally fresh and has a tendency toward idiomorphic form. It is usually polysynthetically twinned according to the albite and pericline laws in rather narrow lamellæ, and these often combine with carlsbad twinning. The index of refrac-

[a] Loc. cit., p. 223.



A. COARSE GRANITIC BRECCIA, BELONGING TO THE GILA CONGLOMERATE AND FORMING SUMMIT OF NEEDLE MOUNTAIN.

B. TYPICAL SURFACE OF SCHULTZE GRANITE, SHOWING SHEETING OR PARALLEL JOINTING: ON TRAIL TO PINAL RANCH, NEAR HUTTON PEAK.

tion is slightly above 1.54, which, taken in connection with the very small extinction angles observed in sections of albite-carlsbad twins in the zone perpendicular to the brachypinacoid, indicates a calcic oligoclase.

The orthoclase occurs as phenocrysts, often irregularly bounded, or peripherally intergrown with oligoclase and quartz, and also allotriomorphically crystallized with quartz between and around the oligoclase in the groundmass. It is fresh and fairly clear and is not noticeably microperthitic, although it contains frequent inclusions of oligoclase, quartz, and biotite.

The biotite, which is black in hand specimens, shows the usual brownish pleochroism and strong absorption of this mineral in thin sections. Cleavage flakes give an axial cross which does not perceptibly open upon rotation of the microscopical stage.

A chemical analysis of a typical sample of the Schultze granite, collected about a mile west of the Schultze ranch, is given under I in the following table:

Chemical analyses of granitites and granite-porphyries.

	I.	II.	III.	IV.
SiO_2	70.95	69.35	68.95	69.73
Al_2O_3	16.30	15.71	15.84	15.97
Fe_2O_3	1.01	1.18	1.14	1.27
FeO	.36	.43	.56	1.23
MgO	.23	.36	.24	.68
CaO	1.85	1.79	1.96	3.28
Na_2O	5.16	4.78	4.56	5.30
K_2O	3.34	3.63	3.69	1.76
H_2O-	.26	1.17	.86	.53
H_2O+	.37	.97	1.49	
TiO_2	.23	.19	.22	....
ZrO_2	Trace.	Trace.	.01	....
CO_2	None.	None.	None.	....
P_2O_5	Trace.	.08	.08	.21
SO_3	Trace.	....	....	....
Cl	Undet.	....	....	....
F	Undet.	....	None.	....
S	Trace.	Trace.	None.	....
Cr_2O_3	None.	None.	None.	....
NiO	Undet.	....	....	....
MnO	Trace.	Trace.	Trace.	....
BaO	.04	.07	.07	....
SrO	Undet.	....	....	....
Li_2O	Undet.	....	....	....
Total	100.10	99.71	99.67	99.96

I. Granitite, 1 mile west of Schultze's ranch; Dr. Eugene T. Allen, analyst.

II. Granite-porphyry, marginal facies of above; 2 miles south of Schultze's ranch; Dr. Eugene T. Allen, analyst.

III. Granite-porphyry, dike; 1 mile southwest of the Hog ranch; Dr. Eugene T. Allen, analyst.

IV. Granitite; Melibocus, Odenwald. Rosenbusch, Gesteinslehre, second edition, 1901, page 79. Cited for camparison.

In its high silica, low iron oxides, magnesia, and lime, and moderately high potash and soda, the analysis corresponds to a granite, while the preponderance of soda over potash points to a soda granite, in which might be expected an alkalic feldspar rich in the albite molecule. But the optical examination, on the other hand, shows that the chief constituent of the rock is oligoclase. Calculating the magnesia, all of the ferrous oxide, and most of the ferric oxide as biotite, and proportioning the remaining potash to the remaining alumina for orthoclase and muscovite after the subtraction of enough of the alumina to form titanite, albite, and anorthite, the approximate mineralogical composition of the rock may be given as follows:

Mineralogical composition of granitite.

Albite molecule [a]	43.83
Anorthite molecule [a]	8.41
Orthoclase molecule	16.82
Quartz	24.09
Biotite	4.50
Muscovite	1.28
Titanite	.43
Iron ore	.64
Total	100.00

Some of the albite molecule is probably combined with the orthoclase molecule to form alkalic feldspar. But as the orthoclase is not microperthitic, and as the composition of the oligoclase as above calculated agrees well with the optical determinations, this amount is probably not large. It thus appears that about half the rock is composed of oligoclase.

It was found in making the foregoing calculation that if all the alumina, after taking out sufficient for the biotite, anorthite, and albite, were combined with the available potash it would give nearly as much muscovite as biotite. This result, as microscopical examination shows, is plainly erroneous, and as the alumina in the analysis is rather higher than is common in rocks of this general chemical character half of one per cent of this oxide was assumed as excessive and thrown in with the remaining iron oxide as iron ore. This is in accord with the well-known fact that small and often unavoidable errors in analysis, espe-

[a] 52.24 per cent of oligoclase, of the approximate composition Ab_3An_1.

cially any occurring in the iron determinations, are cumulatively thrown upon the alumina.

Upon consideration of the chemical and mineralogical compositions together it appears that the rock does not fit into existing schemes of classification. It is chemically a sodium-rich granite, but mineralogically it is about half plagioclase. It is conceivable that under slightly different conditions the calcium might have gone into mineralogical combination to form pyroxene or amphibole instead of oligoclase, and the rock would then have been made up chiefly of alkalic feldspar and could be placed without hesitation among the sodium-rich granites. All things considered, it appears to belong somewhere between the quartz-monzonites and the alkalic granites. It is placed provisionally with the latter for the reason that chemical composition is considered more important in deciding petrological relationship than the particular manner in which the potassium, sodium, and calcium of a given magma enter into mineralogical combination.

The foregoing description applies to what may be termed the typical rock of the Bloody Tanks area—the rock characteristic of the mass as a whole, particularly at some distance from its periphery. Near the latter the typical porphyritic granitoid rock sometimes passes into facies, which, in the absence of a more appropriate name, may be called biotite-granite-porphyry. Such porphyry is characteristic of the area north of Bloody Tanks, drained by Liveoak arroyo, and of the southern border of the granitic area near the schist contact south of the Schultze ranch. The lobe-like projection of the biotite-granite extending northward past Needle Mountain toward Jewel Hill shows much textural variation, passing frequently into facies in which very conspicuous orthoclase phenocrysts lie in a medium granular to fine granular, rather biotitic groundmass. The orthoclase phenocrysts are occasionally 4 or even 5 inches in length, such large crystals always showing rounded outlines and more or less peripheral poikilitic texture.

A typical specimen of the granite-porphyry near the schist contact, 2 miles south of the Schultze ranch, shows idiomorphic phenocrysts of orthoclase and quartz in a fine-grained groundmass consisting chiefly of white feldspar, quartz, and biotite. The orthoclase phenocrysts occur in apparently untwinned individuals of the usual orthoclase habit and have a maximum length of about 2 centimeters. The quartz phenocrysts are of slightly rounded bipyramidal form, and rarely exceed 5 millimeters in length.

Under the microscope the rock shows a typical porphyritic texture. Phenocrysts of orthoclase, quartz, plagioclase (mostly oligoclase), and biotite lie in an extremely fine granular groundmass, such as is common in "quartz-porphyries," but which was hardly expected in a facies of so crystalline a plutonic rock as the granitite of the Bloody Tanks area. The quartz phenocrysts, too, are embayed as is common in rhyolitic effusive rocks. The orthoclase is usually untwinned, idiomorphic, and fairly fresh, although all the feldspars contain some sericite and indeterminable alteration products. The biotite is almost wholly altered to chlorite, epidote, and iron ore.

A chemical analysis of this porphyry is given under II in the table of analyses, on page 69. The practical identity of the magma which solidified as porphyritic biotite-granite in the middle of the batholith and as granite-porphyry at the contact with the schists is apparent from a comparison of analyses I and II. The modification is textural, and perhaps to some degree mineralogical, but there has been no appreciable magmatic differentiation.

The porphyry of Liveoak Gulch has been much shattered, and is often extensively stained with salts of copper. In its petrographical character it is similar to that just described, but all gradations may be found along the Western Pass road near Bloody Tanks, from porphyries with microcrystalline groundmass to the typical biotite-granite of the central portion of the batholith.

The texturally variable rock which forms the lobe extending across the Pinto Creek road south of Jewel Hill differs microscopically from the typical rock of the Bloody Tanks area in the presence, with the oligoclase, of a more calcic plagioclase, in part labradorite of the composition $Ab_1 An_1$. Biotite is also a little more abundant, and titanite, never more than a very sparing constituent in the normal rock, is here a conspicuous accessory mineral, not only in idiomorphic microscopic crystals, but as individuals visible in hand specimens. Iron ore and apatite are also somewhat more abundant than in the usual rock of the area.

The small area of granitic rock intrusive in Pinal schist, at the forks of the Gold Gulch and Pinto Creek roads, is probably merely an apophysis (offshoot) of the main Bloody Tanks mass, which it petrographically resembles.

The rock of the Porphyry Mountain area, as exposed in the upper part of Gold Gulch and on Porphyry Mountain, is a light-gray porphyry resembling that of Liveoak Gulch, and like the latter, it is much fissured and is somewhat generally impregnated with fine pyrite. North of Porphyry Mountain this porphyry grades into a rather coarsely crystalline, crumbling porphyritic granitite which becomes reddish in color as it passes beneath the quartzites of the Apache group.

Under the microscope the porphyry and porphyritic granitite of the Continental area closely resemble the corresponding rocks of the Bloody Tanks area, and both are probably referable to the same magma and to the same period of intrusion.

DIKES CONNECTED WITH THE INTRUSION OF THE SCHULTZE GRANITE.

Occurrence and distribution.—These dikes, which may be classed generally as granite-porphyries, are confined to the southern half of the quadrangle and cut the Madera diorite and the Pinal schists. Some of them, as for example the dike shown on the map about a mile and a half east of the Pinal ranch and the smaller ones shown about 2 miles southeast of the Schultze ranch, are directly connected with the Bloody Tanks granitite mass. Others, such as the irregular dikes extending southwestward from the Hog ranch and the long one south of Lyons Fork, have no visible connection with any parent granitic body. The dikes, even when occurring in the quartz-mica-diorite, show a marked tendency to conform in trend with the general strike of the schists.

The Madera diorite, like most granitic masses of any size, is also cut by light-colored fine-grained aplitic dikes. These are generally too small to map, and as they present no unusual features their further description may be omited from this paper.

Petrography.—The rock forming the middle portions of the larger dikes is a granite-porphyry petrographically identical with the marginal facies of the Bloody Tanks mass already described. In order to place this identity beyond question, a chemical analysis was made of a typical specimen from the Hog ranch dike, collected about half a mile southwest of the latter place. This analysis is given in column III on page 69. Comparison with analyses I and II shows not only that all three rocks are formed by the solidification of one magma, but inasmuch as they represent respectively typical specimens from the middle and margin of a great batholithic mass and from an outlying dike, they indicate as well remarkable chemical homogeneity of this magma solidifying under conditions geologically diverse. This identity alone is enough to show that the Bloody Tanks granitite is younger than the quartz-mica-diorite of the Crest area.

Near their walls the granite-porphyry dikes often pass into nearly white aphanitic facies in which an occasional minute phenocryst of quartz or feldspar may be detected. Under the microscope this marginal variation shows small phenocrysts of oligoclase and orthoclase in felsitic groundmass, which extinguishes in shadowy areas between crossed nicols and is a minutely crystalline aggregate of quartz, orthoclase, and probably other feldspars.

RUIN GRANITE (GRANITITE OR BIOTITE-GRANITE).

Occurrence and distribution.—Between Pinal and Pinto creeks, near the northern edge of the quadrangle, the exposures of granitite fall into three principal and several smaller areas. It is evident however that all are really part of one great mass which forms a continuous basement beneath the faulted remnants of

Paleozoic rocks. Thus the Pinto Creek area in the extreme northwest corner of the quadrangle is undoubtedly part of the same mass as the granitite forming the broad floor of Granite Basin northeast of Webster Mountain; and, although the connection in this case is less obvious, it is highly probable that the granitite of Granite Basin is really continuous with the petrographically identical rock of Ruin Basin.

The granitite of all these northern areas shows the tendency to form relatively broad basins or valleys of erosion in an even more marked degree than the Schultze granite. It is more generally decomposed than the latter rock, and usually somewhat reddish in color, both of which facts are probably due to less extensive erosion below the old pre-Cambrian surface. The surfaces of the larger areas are only moderately rocky and the generally gentle slopes are often covered with what might be termed granite crumbs—a coarse angular sand consisting of particles of quartz. crystals, and fragments of pinkish feldspar, and flakes of biotite derived from the crumbling of the rather coarse-grained granitic rock.

A little coarse reddish granitite correlated with the Ruin granite, is also found about 3 miles east of Gerald's ranch, forming three small areas near the northern edge of the quadrangle.

The Ruin granite is frequently found overlain by the basal conglomerate of the Apache group, resting upon a pre-Cambrian surface of erosion.

Petrography.—The Ruin granite is uniformly of coarse-grained porphyritic texture, with a tendency to crumble into rounded forms from which it is almost impossible to secure fresh hand specimens. Rounded pinkish phenocrysts of unstriated feldspar, often 2 inches in length, and generally showing carlsbad twinning, are conspicuously scattered through a rather coarsely granular groundmass consisting of preponderating white plagioclase, quartz, black mica, and a little pink feldspar. In general texture this rock closely resembles the much fresher, coarsely crystalline, and somewhat biotitic facies of the Schultze granite exposed on the Pinto Creek road near the head of Webster Gulch. The resemblance is so close as to suggest in the field that the rocks were originally identical and that the difference in color, largely due to the pinkish tint of the phenocrysts in the rock of the northern areas, is merely due to longer exposure to weathering.

Under the microscope, however, the large feldspar phenocrysts are found to be a finely microperthitic microcline—a mineral not known in the Bloody Tanks mass. They are micropoikilitic, also, with reference to the other constituents, particularly in their peripheral portions. The groundmass is a hypidiomorphic granular aggregate of quartz, microcline, oligoclase, and biotite, named in order of apparent abundance, with accessory titanite, apatite, iron ore, and zircon.

Creek. Like the Madera diorite and Solitude and Schultze granites, the Lost Gulch monzonite is intrusive into the Pinal schists. Its present boundaries, however, save where overlapped on the east by the Gila formation, are determined chiefly by faults which have dropped the younger rocks so that they abut against the monzonitic fault block (horst).

Petrography.—As it occurs in Lost Gulch, the quartz-monzonite is a fine-granular gray rock, containing scattered phenocrysts of potassium feldspar with smaller ones of plagioclase. In megascopical appearance it closely resembles the Willow Spring granite. Toward the eastern part of the area the rock becomes more closely crystalline and the gray, medium granular groundmass is seen to be made up of potassium feldspar, plagioclase, quartz, and biotite.

Under the microscope the monzonite shows a hypidiomorphic granular texture. Quartz is apparently the most abundant constituent, followed by plagioclase, microcline, and biotite. The accessory minerals are iron ore, titanite, apatite, and an occasional zircon. Both the quartz and the microcline show a tendency toward poikilitic structure. The latter mineral is occasionally slightly perthitic. The plagioclase ranges from calcic oligoclase to andesine.

A chemical analysis of a fresh medium-grained specimen from Lost Gulch, about 2 miles northwest of Black Warrior, is given below under I, while under II is placed for comparison the analysis of an adamellite from Brixen in the Tyrol, as cited by Brögger.[a]

Chemical analyses of quartz-monzonites.

	I.	II.
SiO_2	68.63	69.78
Al_2O_3	13.68	12.79
Fe_2O_3	2.53	5.07
FeO	1.81	
MgO	1.10	1.05
CaO	2.51	2.96
Na_2O	2.94	2.37
K_2O	4.04	3.62
H_2O-	.70	1.58
H_2O+	.87	
TiO_2	.69	....
ZrO_2	.01	....
CO_2	None.	....
P_2O_5	.24	....
Cl	Not det.	....

[a] Loc. cit., p. 62a.

Chemical analyses of quartz-monzonites—Continued.

	I.	II.
F	Not det.	
S	[a](.06)	
NiO	None.	
MnO	.15	
BaO	.05	
SrO	Trace.	
Li_2O	Faint trace.	
FeS_2	.11	
Tota.	100.16	

[a] Included with pyrite.

I. Quartz-monzonite (adamellite). Lost Gulch, Gila County, Ariz. W. F. Hillebrand, analyst.
II. Adamellite. Brixen, Tyrol. Rube, analyst. (Brögger, loc. cit., p. 62a.)

The mineralogical composition of the Lost Gulch monzonite may be calculated from the chemical analyses as follows:

Mineralogical composition of the Lost Gulch monzonite.

	Per cent.
Quartz	31.67
Orthoclase molecule	19.79
Albite molecule	[a]25.03
Anorthite molecule	[a]10.71
Biotite	8.33
Magnetite	2.69
Titanite	1.23
Apatite	.44
Pyrite	.11
Total	100.00

In making the foregoing calculation, the albite and anorthite molecules are united to form andesine, for the reason that the microcline is not noticeably perthitic in the rock analyzed, and the composition of the plagioclase so obtained agrees fairly well with the optical determinations. The Lost Gulch rock is chemically a quartz-monzonite. But in the absence of amphibole or pyroxene, the calcium has all gone into the combination as plagioclase, and consequently this mineral predominates over the microcline nearly as two to one. It is conceivable that practically the same magma might crystallize as an aggregate of quartz, potassium-sodium feldspar, andesine, and diopside, and thus correspond to Brögger's

[a] Equivalent to 35.74 per cent of andesine of about the composition Ab_4An_3.

mineralogical definition of a quartz-monzonite, as a rock in which the orthoclase (or potassium-sodium feldspar), and plagioclase are present in nearly equal amounts. As it is, the rock lies almost exactly on the line between granodiorite and quartz-monzonite according to the distinction made by Lindgren.[a]

WILLOW SPRING GRANITE.

Occurrence and distribution.—This is a small isolated mass lying just north of Webster Gulch and occupying an area of less than a square mile. It is intrusive into the Pinal schists, and, like the Lost Gulch monzonite, is bounded in part by faults.

Petrography.—The Willow Spring granite is gray in color and usually fine grained for a rock of granitic composition, the average size of the grains being less than a millimeter. Occasional phenocrysts of orthoclase or microcline occur scattered through this often nearly aphanitic groundmass.

The microscope reveals a hypidiomorphic granular aggregate consisting of abundant quartz and microcline with oligoclase, muscovite, and biotite. The exact nature of the oligoclase is not readily determinable, owing to the general decomposition of this constituent into nearly cryptocrystalline aggregates, apparently consisting principally of kaolin. The accessory minerals are apatite, iron ore, and tourmaline, none of them being abundant. The secondary minerals are kaolinite, epidote, and chlorite.

The exact petrological relationship of the Willow Spring granite remains somewhat in doubt. It is quite possible that it may be more closely connected with the neighboring quartz-monzonite of Lost Gulch than with the Solitude granite.

AGE AND SEQUENCE OF THE GRANITIC ROCKS.

All of the granitic rocks of the Globe quadrangle are pre-Cambrian, but are younger than the Pinal schists into which they are intrusive. The extensive development of gneissic structure in the Madera diorite and its absence in the other granitic rocks point to the earlier age of the former. The Madera diorite is certainly older than the Schultze granite, for it is cut by dikes from the latter. The Solitude granite is also cut by similar dikes and is accordingly older than the Schultze granite, although probably younger than the Madera diorite. The evidence for the latter relation, however, is far from conclusive, and depends chiefly upon the more gneissic structure of the supposedly older rock.

The relative ages of the Willow Springs granite and Lost Gulch monzonite are unknown. It is almost certain that they are younger than the Madera diorite, but whether they are younger or older than the Schultze granite has not been

[a] Am. Jour. Sci., 4th series, Vol. IX, 1900, pp. 277-281.

determined. The age of the Ruin granite is also somewhat in doubt, but on account of their close petrographical resemblance the Schultze and Ruin granites are thought to be of practically the same age.

CONTACT METAMORPHISM IN CONNECTION WITH THE GRANITIC INTRUSIONS.

Distinct contact metamorphism is found only in connection with the Madera diorite. The other granitic rocks were intruded into already metamorphosed and crystalline schists, and have consequently produced no change that can be clearly distinguished from an earlier and more general metamorphism.

While the intrusion of the Madera diorite resulted in undoubted contact phenomena, it is rather difficult to discriminate between these and the broader metamorphism whereby a series of sedimentary rocks were transformed into crystalline schists. Andalusite and sillimanite, characteristic contact minerals, are frequently present in the coarsely crystalline and rather massive muscovite-schists near the quartz-mica-diorite, but are not found in the laminated sericitic schists at a distance from the eruptive rock. Black tourmaline, while not uncommon as a microscopical constituent of the schists, is particularly abundant near the eruptive contact associated with quartz in veins and veinlets. In addition to the development of these minerals, which are characteristic of granitic contact zones, the general crystalline texture of the schists is plainly related to the intrusion of Madera diorite. Near the latter the schists are coarsely crystalline, rather massive, and have lost all traces of original clastic structure. Away from the Madera diorite they become finely crystalline, fissile, and occasionally retain in part the structure of pebbly grits. It is probable that the metamorphic action of the quartz-mica-diorite was not confined to the production of a well-defined contact zone, but was an important factor in transforming the sedimentary beds as a whole into crystalline schists. That later metamorphic forces have also been effective in imposing its present character upon the pre-Cambrian complex, is shown by the considerable development of gneissic structure in the Madera diorite itself.

METADIABASE.

Definition.—By metadiabase is meant a diabase which has undergone mineralogical change, although its original character is not wholly obliterated.

Occurrence and distribution.—The name metadiabase might with justice be applied to certain uralitic facies of the rock described in this report as diabase. For the sake of clearness and convenience, however, it is restricted to a small area of more conspicuously altered rock which lies 1¾ miles east of Schultze's ranch and which is older than the characteristic diabase of the region. Very little of this rock is exposed and, as it passes beneath the Gila formation, its actual extent is not known.

Petrography.—The metadiabase is very dark green and rather coarsely crystalline, the feldspar being so dark in color as to superficially resemble amphibole. A striking peculiarity of the rock is the occurrence of numerous inclusions of white quartz—apparently vein quartz. These fragments are conspicuously corroded and embayed, and are surrounded by reaction rims of amphibole, visible to the unaided eye.

The microscope shows the rock to be a rather coarsely crystalline ophitic aggregate in which the usual place of the augite is taken by nests of light-green amphibole with a little biotite, apatite, and iron ore. The feldspar is apparently a calcic labradorite and although fairly fresh, is brown in transmitted light, the color being due to thickly crowded minute rods and dark dust-like particles. The amphibole does not merely occupy the spaces between the feldspars, but prisms of the former mineral often project into the latter. Although the general character of the alteration is similar to ordinary uralitization, yet there is a suggestion that the diabase of this mass, like the andalusite-bearing granite adjoining it, has been subjected to contact metamorphism, which appears to have been a local effect of the intrusion of the granitite of the Bloody Tanks area. The quartz inclusions are granular aggregates having the common microscopical character of vein quartz and are enveloped in green amphibole, the small prisms of the latter mineral standing generally perpendicular to the surface of the quartz. The source of these inclusions is not known.

Age.—The metadiabase is cut by granite-porphyry dikes from the Bloody Tanks granitite, which is considered as probably of pre-Cambrian age. The metadiabase is therefore pre-Cambrian and much older than the diabase next to be described.

DIABASE.

Definition.—Diabase is an eruptive rock, usually intrusive, and consists essentially of a crystalline aggregate of calcic plagioclase (which may range from labradorite to anorthite) with pyroxene, frequently a little biotite and usually olivine. When the latter mineral is present, the rock is commonly termed an olivine diabase. The ordinary accessory constituents are magnetite (usually titaniferous) and apatite. The texture of diabase varies from aphanitic to coarsely crystalline, and as seen under the microscope is ophitic, that is, the pyroxene (usually augite) fills angular spaces between the partly idiomorphic crystals of plagioclase. Diabase is usually a heavy rock with dark-gray or greenish color. In the Globe district the diabase, really an olivine-diabase, is commonly called "diorite" by the miners.

Occurrence and distribution.—Diabase occurs intrusive into all the rocks of the Globe region from the pre-Cambrian schists and granitic batholiths up to and including the Globe limestone, as sills (intrusive sheets) ranging from a fraction of an inch to several hundred feet in thickness, as irregular masses cutting across the stratification of the invaded rocks, and as small dikes.

Owing to the numerous faults that traverse the region, it is impossible to determine the number, thickness, and former continuity of the diabase sills. They appear to have been intruded at different stratigraphical horizons in rocks already much faulted. Thus in one portion of the quadrangle certain beds of the Apache group may be separated by a sill 400 feet thick, while a few miles away the same beds will be found in undisturbed sedimentary contact with smaller sills above or below in the stratigraphical column.

One or more sheets varying greatly in thickness are usually found cutting the pre-Cambrian schistose and granitic complex, about 200 feet below the basal conglomerate of the Apache group and lying roughly parallel to the stratification of the latter. Such a sill appears in the southeastern corner of the quadrangle. Another of irregular shape, possibly originally a continuation of the foregoing, is shown near the edge of the map (Pl. I) southwest of Pinal Peak. North of Webster Mountain there is a relatively thin sill, 50 or 75 feet in thickness, occurring less than 50 feet below the base of the Apache group, and in the northwestern corner of the quadrangle the granitite is cut by two or more sills at varying distances up to 200 or 300 feet below the old pre-Cambrian erosion surface. These sills are so irregular and have been so faulted as to render their original number, thickness, and position with reference to the Apache sediments which formerly overlaid them rather conjectural.

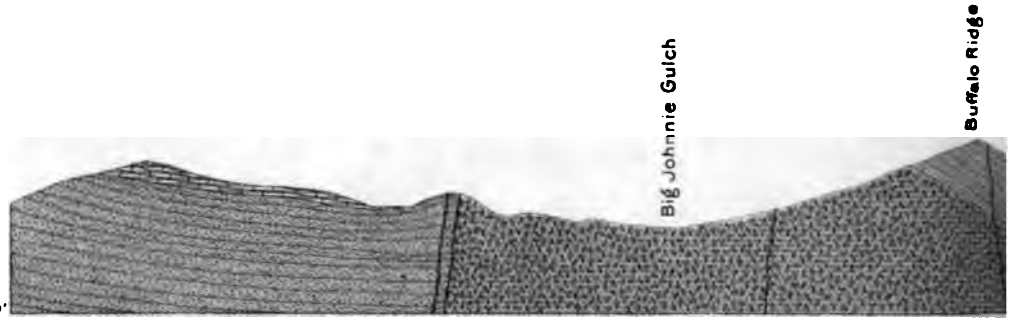
Similar sills occur in the biotite-granite near the edge of the quadrangle north of Globe, and they may generally be found wherever the granitic rocks which underlie the Apache group are extensively exposed.

The diabase masses, however, attain their greatest bulk and importance within the stratified rocks of the Apache group and Globe formation. Their intrusion into these quartzites and limestones was accompanied or preceded by extensive faulting which divided the strata into numerous blocks. The molten magma not only forced its way as sills between the strata of the individual blocks, but filled the fault fissures and drove the blocks apart. Masses of limestone and quartzite were thus completely enveloped in the invading molten rock and often shifted bodily to an extent which at first view seems scarcely credible. The magma was able to overcome those forces of gravity or compression tending to hold the blocks of strata together, and to float them apart. Although the process can not be exactly paralleled by any familiar simile, it may be partly likened to the break-up and movement of thick ice by a spring flood.

The largest area of diabase within the quadrangle is that extending northward from the Old Dominion mine, and from it may be drawn several illustrations of the general mechanical effect of the intrusion. Scattered over this area, particularly west of Ramboz Peak, are little masses of quartzite belonging to the Apache group, and composed of strata dipping generally to the southwest. Some of these masses are bounded in part by faults, but many of them are separated from the diabase by eruptive contacts. They are not merely remnants of an overlying sedimentary cover, now largely stripped away from the diabase by erosion, but they are detached, irregular blocks of more or less contorted strata, isolated in the eruptive rock. Most of them are inclusions, in fact, brought to light by the erosion of the diabase which formerly completely inclosed them. Such is the mass of quartzite at the Big Johnnie mine on the western slope of Black Peak. It is made up of beds dipping gently to the south, underlain and overlain by diabase, from which it is separated by intrusive contacts. The sheet of diabase here lying on top of the quartzite and forming the summit of Black Peak has a thickness of at least 300 feet, while it is not known how much more has been removed by erosion. In the workings of the Grey mine in Copper Gulch masses of quartzite and limestone strata were found irregularly distributed in the diabase down to the sixth level, at a depth of about 300 feet. Below this the shaft is in diabase for 400 feet, although blocks of inclosed strata may possibly be encountered when drifting is begun. About half a mile east of the saddle at the head of Copper Gulch (Pl. XV) a considerable body of limestone strata belonging to the Globe formation is inclosed by the diabase, while just south of the limestone, at an elevation of about 300 feet above it, the same mass of diabase passes with an intrusive upper contact beneath conglomerate, grits and quartzite of the Apache group. Stratigraphically the limestone belongs above the quartzite, but here it lies enveloped in the diabase at least 500 feet below its normal position. A similar condition exists in the Old Dominion mine, as shown in fig. 7, a block of limestone occurring isolated in the diabase that forms the general foot wall of the Old Dominion fault. Similar examples of the displacement and isolation of blocks of strata at the time of the diabase intrusion might be cited from other parts of the quadrangle. Some of these are evident from an inspection of the general geological map (Pl. I), but the detailed description of all is not necessary.

So far as its upper contact is preserved, the great body of diabase north of Globe has the general character of a thick sill or laccolith. On Buffalo Ridge and elsewhere the intrusive rock passes under the quartzites with a contact which

A
3200'



B
3400'

C
3800'

SEDIMENTARY

EARLY PLEISTOCENE (?)

DEVONIAN AND CAR

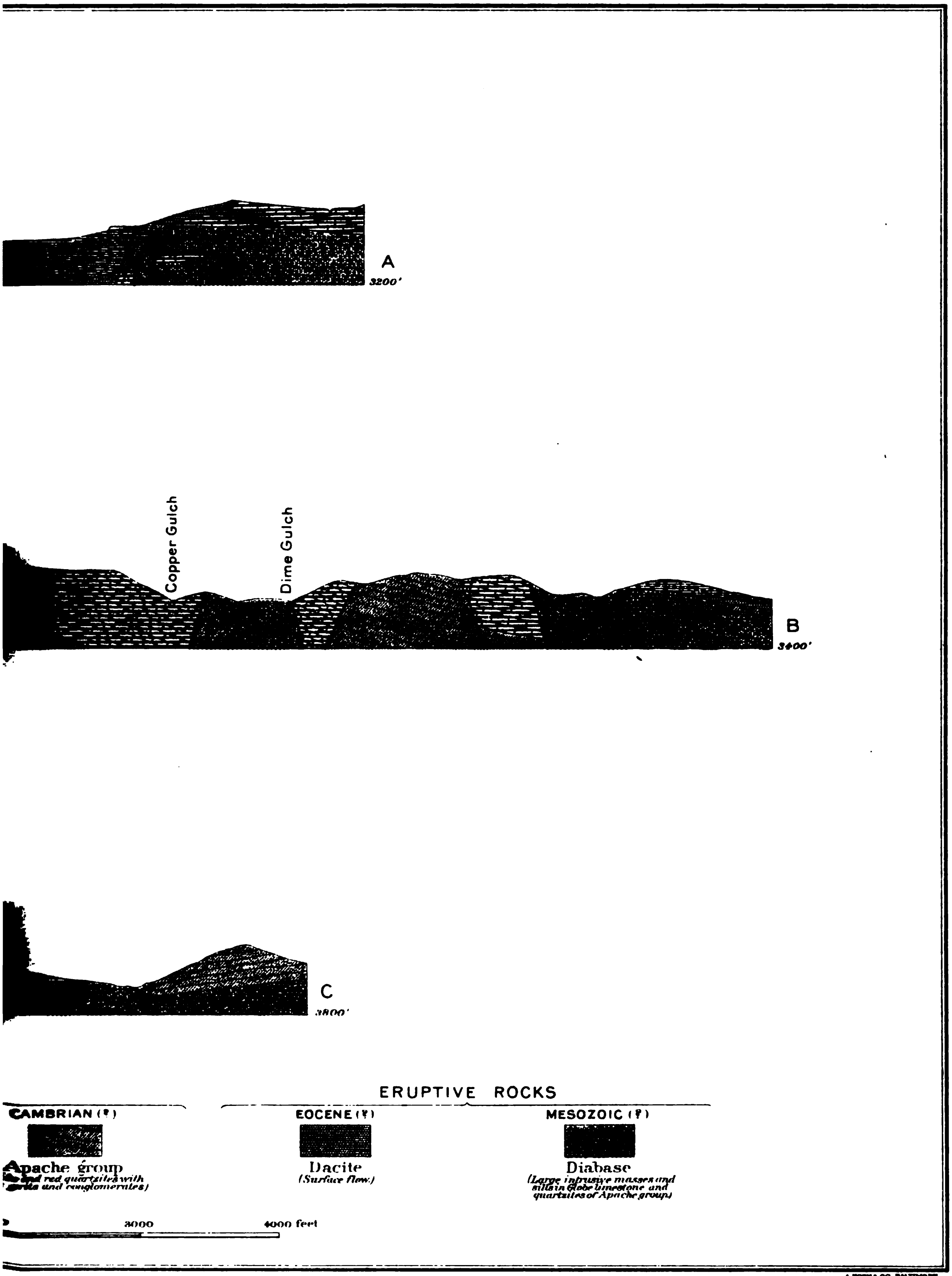
Mine and smelter dumps.

Gila conglomerate
(Irregularly bedded variable fluviatile conglomerates)

Globe limes

1000 500 0

GEOLOGICAL SECTIONS



NDICATED ON PLATE XV

in general follows a bedding plane. But even as regards its upper surface, this irregular mass, which forced itself into and around the blocks of faulted strata, is a sill only in a very general way. Of its lower surface nothing is known. Although in other parts of the region and in the canyon of the Salt River to the northwest of the quadrangle the diabase forms distinct sills, none of them are demonstrably so thick as this mass, which, if we disregard the blocks of included strata, is shown by the workings of the Old Dominion and Grey mines to reach a thickness of over 800 feet. Whether it rests upon the lower beds of the Apache group or has followed in general the pre-Cambrian surface upon which the sediments were laid down, or whether it extends downward as a batholith to indefinite depths, are questions which can not at present be answered.

Petrography.—When fresh, the diabase typical of all the larger areas in the quadrangle is a tough, heavy, dark-gray holocrystalline rock of medium grain. The minerals readily visible to the unaided eye are plagioclase, augite, and iron ore. The augite is often particularly noticeable on natural surfaces of the rock, as it forms flashing poikilitic blotches, sometimes 2 centimeters in breadth. The weathered rock is usually greenish, and the diabase masses can often be distinguished from a distance by the dark-olive hue of their bare slopes. Hard residual nodules of various sizes and curious nodular surfaces are extremely characteristic of the disintegration of the typical diabase. The rock crumbles to a greenish sandy soil (saprolite), embedded within which are residual kernels of sound rock ranging in size from that of a pea up to a foot or more in diameter. (Pl. XVII, *A*.) The larger masses have very characteristic lumpy or warty surfaces, and with the further progress of disintegration these lumps separate as small nodules. Close examination of these little bodies shows that their form and resistance to disintegration is dependent upon the presence of rounded poikilitic crystals of augite. In addition to the knobs, with which exposed surfaces of the diabase are usually studded, there are sometimes present well-marked projecting ribs or ridges an inch or two in height. These are due to the development of secondary hornblende along minute fissures in the rock and the resistance of this mineral to weathering.

Thin sections examined under the microscope show a perfectly fresh ophitic aggregate of calcic labradorite or bytownite, faintly brownish augite, olivine, and a little biotite, iron ore, apatite, and titanite. In many cases—as, for example, the rock on the summit of Black Peak—the diabase is so fresh that the olivine, which occurs in the usual rounded forms more or less inclosed in the augite, shows scarcely a trace of serpentinization. The augite is broadly poikilitic, the apparently isolated angular areas between the partly idiomorphic crystals of plagioclase showing optical continuity over a large part of the microscopic slide. The angle $c:\mathfrak{c}$ is approximately 45°.

A chemical analysis of a fresh typical specimen from a hilltop 1 mile northwest of Black Peak is given below:

Chemical analysis of diabase.

[Dr. E. T. Allen, analyst.]

SiO_2	49.00
Al_2O_3	16.87
Fe_2O_3	2.09
FeO	8.50
MgO	6.70
CaO	10.21
Na_2O	2.57
K_2O	.66
H_2O-	.72
H_2O+	1.00
TiO_2	1.11
ZrO_2	.02
CO_2	None.
P_2O_5	.13
SO_3	None.
Cl	.05
F	Undet.
S	None.
Cr_2O_3	.02
NiO	None.
MnO	.10
BaO	Trace.
Li_2O	Undet.
SrO	None.
Vd_2O_3	Trace.
Total	99.75

Without knowledge of the exact composition of the augite, it is impossible to make from the chemical analyses an accurate calculation of the quantitative mineralogical composition of the rock. Rough calculation, however, checked by optical estimation in thin sections, indicates a composition of about 55 per cent of bytownite, 30 per cent of augite, 10 per cent of olivine, and 5 per cent of biotite, iron ore, titanite, and apatite. The rock may be considered a typical olivine-diabase.

Although the diabase maintains its general character and appearance far beyond the bounds of the Globe quadrangle, it is subject to certain local variations. In part these are due merely to alteration, the olivine being serpentinized and the augite wholly or partly changed to green uralitic amphibole. Every large mass of the diabase is made up in part of such uralitic facies, and some of the smaller bodies are more or less uralitic throughout.

Near the intrusive contact of the diabase with other rocks, the former often exhibits well-marked textural variation. It is generally more finely crystalline show no preceptible alteration at the diabase contact. In one case, however, for a distance of 15 feet or more from the contact, the quartzite was observed to be thickly speckled with small greenish spots which the microscope showed to be little nests of chlorite. But as these spots are very similar to the little spherical aggregates of sericite (described on page 36), which are not clearly connected with the intrusion of the diabase, it is by no means certain that they are really a contact phenomenon.

Age.—Since the large sills are intrusive into the Globe limestone as well as into the Apache group and older rocks, the main diabasic eruption must have taken place after the close of the Carboniferous. The whole region was afterwards faulted and greatly eroded before the eruption of the dacite, the latter event being assigned with some probability to the Tertiary. The great diabase intrusions are accordingly referred provisionally to the Mesozoic, although there are no data available to fix within that era the particular period to which they belong.

The age of the dark-colored nearly aphanitic dikes and small intrusive masses occurring in the pre-Cambrian complex is not directly determinable. Their geological position leaves it uncertain whether they belong to the intrusive period represented by the diabase sills, or to the much later date of the postdacitic eruption of olivine-basalt described on pages 95 to 97. The distinction has accordingly been made on petrographical grounds, certain fresh, more or less glassy masses, such as that just north of the Pinal ranch, being correlated with the later eruption and colored on the map as olivine-basalt, while the more coarsely crystalline uralitized dikes are considered as probably contemporaneous with the diabase sills. The magmas of the two eruptions were practically identical.

DIORITE-PORPHYRY.

Definition.—By diorite-porphyry is usually meant a holocrystalline intrusive rock having the chemical and mineralogical composition of diorite, but characterized by porphyritic structure, with a well-defined fine-grained groundmass. The rocks here described under this head are generally decomposed, and it is not certain that all of them were originally typical diorite-porphyry.

Occurrence and distribution.—The diorite-porphyry occurs most characteristically as sills, ranging in thickness from 1 to 50 feet, in the lower, shaly member of the Apache group, and less frequently as dikes and small irregular intrusive masses. Small sills are also occasionally found intruded between the beds of the Globe limestone and in the granitic rocks just below the base of the sedimentary series. On account of their small size, the sills are not shown on the geological map. They are rarely absent, however, from the lower part of and its occurrence as regular and often thin sills in blocks of strata which have been faulted and shifted about at the time of the diabasic intrusion, strongly suggests that a part of the porphyry, particularly that which may be provisionally termed quartz-diorite-porphyry, represents a period of eruptive activity anterior to the great invasion of diabase, and consequently that the more or less decomposed intrusives here described as diorite-porphyry are not all of the same age.

EFFUSIVE ERUPTIVE ROCKS.

DACITE.

Definition.—The dacites are porphyritic effusive rocks in which crystals of plagioclase, quartz, and hornblende or biotite, as the common essential minerals, are embedded in a more or less glassy groundmass. The biotite-dacites are closely related to the rhyolites, which they often much resemble. The relation of the dacites to the rhyolites and andesites among the volcanic rocks is similar to that of the quartz-diorites to the granites and diorites among the plutonic rocks.

Occurrence and distribution.—Owing to its abundance, peculiar weathering, and often striking topographical expression dacite is one of the most conspicuous rocks in the region, familiarly known to ranchman and miner alike as "trachyte." It forms one or more effusive sheets or flows, often locally associated with underlying beds of tuff. The original continuity which this flow probably possessed has been greatly obscured by faulting. The maximum thickness is unknown, but existing remnants show that it must have exceeded 1,000 feet. In spite of vigorous post-dacitic deformation of the region, it is clear that the flow was poured out over an irregular surface in whose ravines and valleys the Whitetail formation had previously accumulated.

As it is one of the youngest rocks in the quadrangle and is of fairly resistant nature, the dacite is found capping many of the hills under 6,000 feet in elevation, particularly in the northwestern part of the area. It lies upon various rocks, many of which are soft and easily eroded, and the dacite is consequently a frequent cliff maker and responsible for much of the minor ruggedness of the topography. In natural exposures the dacite varies in color from light pinkish-gray to nearly black. It has a tendency to weather into large, rounded, bowlder-like masses, forming characteristically rocky surfaces, which, as Pl. XVII, *B*, shows, are difficult of traverse. These loose masses are frequently over 6 feet in diameter, and, owing to differential weathering of glassy and lithoidal portions of the rock, often show curiously pitted exteriors. The origin of the bowlders is traceable to a rather irregular division of the rock into rude cuboidal blocks by systems of joints, which are often not visible until brought out by initial disintegration.

Such joints can be well seen in the cliffs along Mineral Creek at the Sixtysix ranch, where various intermediate stages may be observed between angular joint blocks and rounded bowlders. As a rule, the weathering of the dacite is a very superficial process, being confined to the disintegration of exposed surfaces. Decomposition has rarely penetrated the rock for more than a fraction of an inch.

By far the most abundant facies is a light pinkish, inconspicuously porphyritic biotite-dacite, which preserves great uniformity of color and texture over the entire region. This is the rock to which the name "trachyte" is erroneously but unanimously applied by the people of Globe. Of far less abundant occurrence is a dark-gray, glassy facies, often showing distinct flow banding, and of typical vitrophyric structure, which is frequently found at the base of the dacite. It is merely the quickly cooled glassy bottom of the lava flow. It is not always present, but when it does occur, it invariably intervenes between the pink dacite and the underlying rocks. Beneath this vitrophyre, and not always easily separated from it in the field, are certain local accumulations of bedded dacitic tuffs. These are soft, often plainly detrital rocks, ranging in tint from white to pale lemon yellow or gray. They were laid down in small local basins, and are often absent, the dacite resting directly upon the older rocks.

The largest mass of dacite occurring in the Globe quadrangle lies in its southwest corner. This is the rock which forms Hutton Peak and through which Mineral Creek has cut its narrow gorge south of the Sixtysix ranch. It is continuous with the dacite just north of the Pinal ranch and extends for a considerable distance beyond the bounds of the quadrangle to the west. The entire mass is apparently part of a single flow which has undergone deformation and erosion. It culminates at 5,608 feet in Hutton Peak and slopes gently southward, with the exceedingly rugged surface characteristic of this rock. Near the Pinal ranch the dacite rests on granite, the surface of the latter having been irregularly eroded before the eruptive rock covered it. Southeast of Hutton Peak it rests upon the Pinal schists. The mass of the flow is composed of the pink biotite-dacite, but the darker, more glassy, and highly vitrophyric facies described on page 93 is frequently found where the base of the flow is exposed. This variety is usually less than 10 feet in thickness and is apparently an integral part of the main flow. It is not always present, and pink dacite sometimes rests directly upon the granite or schist.

The quartzites occurring south of Mineral Creek, between the Sixtysix ranch and Government Spring, and forming the northern end of the Dripping Spring Range, appear to have formed an island-like mass around which the dacite flowed and which it possibly formerly buried.

In the northwestern part of the quadrangle the principal body of dacite is that culminating in Webster Mountain. This is evidently a very thick portion of the flow as shown by the canyons that have been excavated in it without exposing its base. The area is partly inclosed by peripheral faults whereby this portion of the flow has been relatively dropped with reference to the surrounding older rocks, and its edges in some places brought against the latter. The bounding slopes of this fault block, particularly on the west, north, and east, are often precipitous and good exposures of the bottom of the flow are rare. The rock is the prevailing pink dacite, but the dark vitrophyric facies which occurs only at the bottom of the flow is exposed on the east slope of Webster Mountain and at the head of Willow Spring Gulch.

Considerable masses of dacite occur along Pinto Creek, forming picturesque cliffs south of Horrell's ranch, and the same rock forms the pinnacles and abrupt western wall which look down into the gorge of Pinto Creek south of the mouth of Gold Gulch.

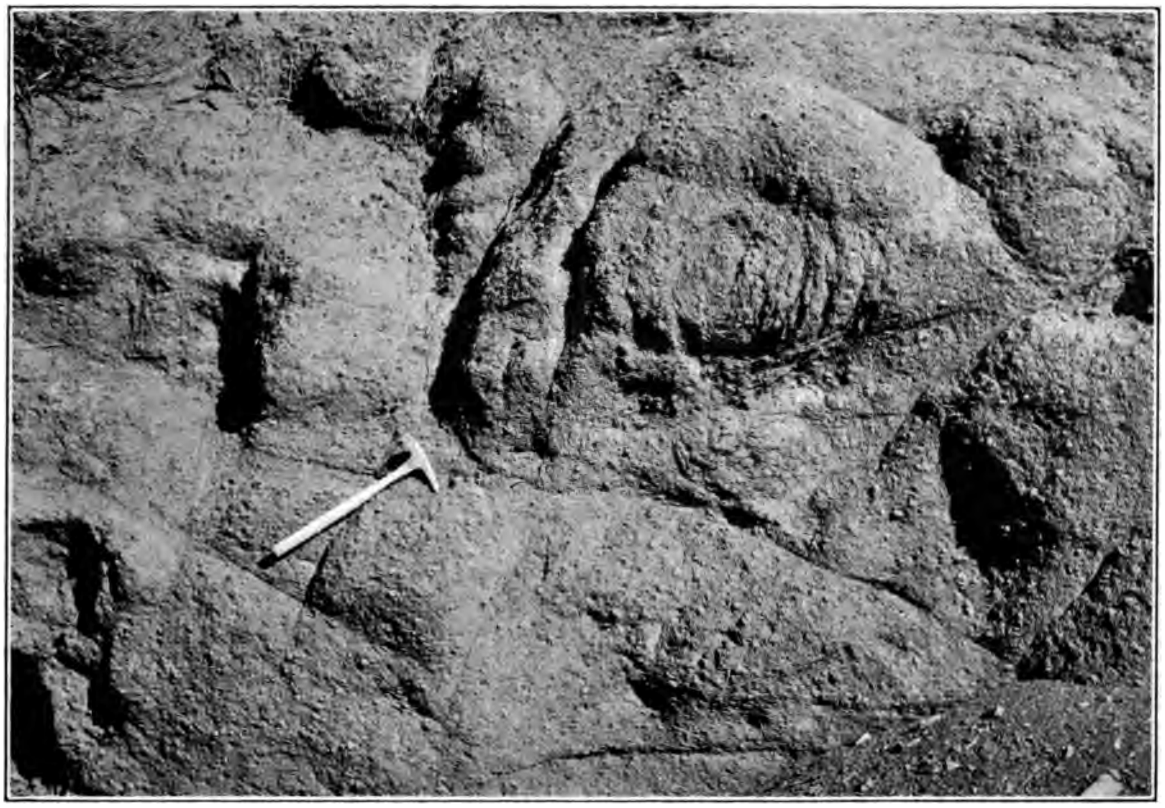
Pink biotite-dacite caps most of the higher hills, including Sleeping Beauty Peak, in the much faulted country between Webster Mountain and Pinal Creek. The bluffs overlooking this creek west and south of Horrell's home ranch are, as the map shows, the eroded edge of a much warped and probably faulted fragment of the flow, which rests on diabase and forms an apparent synclinal basin, open to the south and filled with Gila conglomerate.

Half a mile southwest of Black Warrior the massive dacite rests upon 40 or 50 feet of tuff containing many fragments of the underlying Pinal schists. The ores of the Geneva, Dadeville, and Montgomery claims occur in this tuff. The area on the south slope of the hill west of Black Warrior, colored on the map (Pl. I) as dacite, is composed chiefly of this tuff, most of the overlying massive dacite having been eroded away.

North and east of Globe the dacite flow is represented by an irregular and interrupted remnant which overlies quartzite, limestone, and diabase, and dips gently southwestward under the Gila conglomerate. This outcrop attains a maximum width of about three-quarters of a mile north of the Old Dominion mine. It lies upon an uneven surface and was considerably eroded before the Gila formation was deposited, since the latter rests directly on limestone and quartzite southeast of the mine. A single tiny remnant of the dacite, occupying a little saddle in quartzite, 5½ miles north of Globe, and at an elevation of 4,500 feet, is the only vestige of the former extension of the lava flow over the extreme northeastern portion of the quadrangle.

In the southeast quarter of the quadrangle the dacite does not occur.

Petrography.—The color of the freshly fractured dacite is light gray, usually



A. TYPICAL WEATHERING OF DIABASE; ON ROADSIDE NEAR PIONEER.

B. CHARACTERISTIC SURFACE OF DACITE, NORTH OF THE OLD DOMINION MINE.

The biotite is the common, conspicuously pleochroic variety, with the strong absorption usual in andesitic rocks. It sometimes shows magmatic alteration, which has involved not only the outer surface of the crystal but its whole mass. This altered mica has lost part of its color and pleochroism, the lamellæ have frayed out at the ends and split apart, and the whole is filled with specks of opaque iron ore.

Intergrowths between the different phenocrysts are sometimes met with. Quartz and andesine rarely form micropegmatite, and andesine or labradorite are occasionally intergrown. The accessory constituents are a green hornblende, occurring in small prismatic crystal fragments, apatite, titanite, zircon, and a little magnetite.

The groundmass of the dacite is glassy, and notwithstanding the thickness which the flow must have attained, never exhibits more than incipient crystallization. Globulites, trichites, feldspathic microspherulites, and an indeterminate ferritic dust which renders the groundmass semiopaque and gives the pink tint to the rock are common. In some cases the groundmass shows the minutely divided and shadowy double refraction characteristic of the devitrification of siliceous glasses into obscure aggregates of quartz and feldspar. But distinct well-formed crystals of younger growth than the evidently intratelluric phenocrysts do not occur. The rock is a vitrophyric biotite-dacite, and belongs with the hyalo-dacites of Rosenbusch.[a]

A chemical analysis, made by Dr. E. T. Allen, of a typical specimen of the dacite collected a quarter of a mile north of the Old Dominion mine is given below under I, while under II is placed an analysis of a biotite-hornblende-dacite from the Washoe district, Nevada, for comparison.

Chemical analyses of dacites.

	I.	II.
SiO_2	68.76	69.96
Al_2O_3	15.48	15.79
Fe_2O_3	2.50	2.50
FeO	.44	([b])
MgO	.56	.64
CaO	2.23	1.73
Na_2O	3.89	3.80
K_2O	3.88	4.12
H_2O-	.79	[c]1.53
H_2O+	.57	

[a] Massige-Gesteine, 3d ed., pp. 844–848. [b] With Fe_2O_3. [c] By ignition.

The other accessory minerals are zircon, apatite, titanite, and iron ore as in the common lithoidal dacite.

Occasionally there is found associated with the gray vitrophyre just described a yet more glassy facies. This is a gray brittle volcanic glass of greasy luster in which can be seen small phenocrysts of fresh feldspar, quartz, and biotite. Under the microscope the rock appears as a colorless perlitic glass containing scattered phenocrysts of plagioclase, orthoclase, quartz, and biotite, and minute microlites of feldspar.

The tuffs which have been described as occurring locally at the base of the massive dacite are nearly white rocks, which are sometimes exceedingly troublesome to separate in the field from the overlying massive dacite. This separation is particularly difficult in the case of a white or slightly pinkish tuff which immediately underlies the gray vitrophyric dacite at several points in the northwestern part of the quadrangle. This is a firm rock, showing small crystals or fragments of feldspar, quartz, and biotite in an abundant, uniformly fine-grained base. It might easily be taken for a massive lithoidal rhyolite. Under the microscope, fractured or corroded crystals of plagioclase, biotite, hornblende, and quartz lie thinly scattered in a dusty, gray, glassy groundmass which somewhat indistinctly reveals the reentrant curves and sharp points of minute glass sherds—the characteristic structure of glassy volcanic ash. With nicols crossed, it is seen that very little true glass remains, the groundmass having been changed by devitrification into a very minute aggregate of indefinite and shadowy crystal forms. Calcite, unknown in the massive dacite, is here abundant, not only throughout the devitrified glassy base, but as an alteration product of the plagioclase. In this alteration there is none of the general clouding and breaking down of the feldspar, as is often seen in weathered rocks, but the calcite is separated by a sharp boundary from the perfectly clear and fresh plagioclase at the expense of which it is forming.

The tuffs occurring below that just described are usually plainly clastic rocks of light-gray or pale-yellow tints, varying in lithological character from point to point. The microscope shows them to be glassy volcanic ashes, containing fragments of the same minerals that occur as phenocrysts in the dacite, with occasional particles of diabase or other foreign rock, inclosed in a devitrified glassy base. They usually contain abundant calcite.

Age.—There are no available data for fixing the exact date of the dacitic eruption. It is known to have occurred long after the supposedly Mesozoic intrusions of diabase, for the latter rock was extensively eroded before being covered by the dacite. On the other hand, it clearly antedated the development of the present topography. The dacite is therefore considered, provisionally, of

Tertiary age. According to an oral communication from Mr. Lindgren, a very similar rock occurs at the base of the extensive volcanic series at Clifton, indicating that it may belong to the earlier part of the Tertiary.

BASALT.

Definition.—Basalt is a dark heavy rock of the same chemical and mineralogical composition as diabase, but usually finely crystalline and often showing vesicular or glassy facies. This rock is of widespread occurrence in the form of effusive, or surface, flows, and as small dikes.

Occurrence and distribution.—The largest mass of basalt within the quadrangle occurs near its western border, as a flow, from 50 to 150 feet thick, intercalated in the Gila conglomerate south of Gold Gulch. Other small masses occur between Gold Gulch and Horrell's west ranch. One of the latter is a sheet about 10 feet thick, forming a small area on the crest of a dacite ridge, about 2 miles northwest of the Continental mine. It rests directly upon the pink dacite, and, although darker in color, weathers in similar rounded masses. It may possibly represent a local eruption. Other bodies occur at lower elevations to the southwest of the ridge. The relation of these to the dacite is not clearly shown. They overlie the Whitetail formation and apparently underlie the dacite, but whether they represent a thin intrusive sheet or a predacitic surface flow could not be determined. Inasmuch as the known occurrences of similar basalt are in this region postdacitic, these small masses are provisionally regarded as intrusive, and as contemporaneous with the basalt flow south of Gold Gulch. It is not unlikely, however, that future work to the west of this quadrangle may establish the existence of a predacitic basalt flow. On Manitou Mountain, overlooking Pinto Creek, small intrusive masses of the basalt have broken through the granitite and schist, and probably mark the vents whence the basaltic flow issued. In the southwest portion of the quadrangle are two small intrusive masses of basalt which are petrographically somewhat different from the masses above described, and may possibly belong to a different period of eruption. These form the area just north of Pinal ranch and the tiny body which cuts the granite-porphyry of the Hog ranch dike. It is possible, too, that some of the smaller aphanitic dikes occurring in the schists and granitic rocks of the main Pinal Range, are to be correlated with the basaltic rather than the diabasic eruption.

Petrography.—The flow south of Gold Gulch, the small mass on the dacite ridge to the north, and the intrusive bodies of Manitou Mountain are all composed of typical, dark-gray olivine-basalt, showing small phenocrysts of feldspar, augite, and olivine, with occasional blebs of dark glass, in a dense, nearly aphanitic, groundmass. The olivine phenocrysts are often partly altered to brown pseudomorphs of iddingsite. The basalt of the main flow is often vesicular, many of the vesicles being filled with calcite. The rock of the doubtful masses occurring between the Whitetail formation and the dacite is a somewhat decomposed grayish basalt in which the olivine phenocrysts have been wholly altered to soft, earthy, ferruginous pseudomorphs, with a frequent bronze luster. The rock is very similar in appearance to the carmeloite of Monterey, Cal.

Under the microscope the rock of all the areas, with the exception of those at the Pinal ranch and southwest of the Hog ranch, appears as a perfectly normal olivine-basalt, in which phenocrysts of olivine, anorthite, and augite, in varying proportions, lie in a usually holocrystalline, intersertal groundmass, consisting of anorthite laths, augite, and iron ore. All the minerals are fresh, with the exception of the olivine, which shows various stages of alteration into the usual reddish-brown iddingsite, fibrous green serpentine, and more obscure products.

The rock of the Pinal ranch area is dark gray, nearly aphanitic, and so traversed by rusty, conchoidal fractures as to render the collection of a sound hand specimen very difficult. The microscope shows a few minute lath-shaped phenocrysts of anorthite lying in a hyalopilitic groundmass made up of microlites of plagioclase, grains of augite and iron ore, and glass. Olivine was not recognized.

The basalt of the small mass intrusive in the Hog ranch dike is a little more coarsely crystalline than that near the Pinal ranch, and shows small, porphyritic crystals of augite and plagioclase, just visible to the unaided eye. Under the microscope, the thin sections show small rounded phenocrysts of augite and olivine, with laths of anorthite, lying in a very fine holocrystalline groundmass of feldspar microlites, with granules of augite, olivine, and iron ore. Of rare sporadic occurrence are phenocrystic grains of corroded quartz surrounded by reaction rims of augite with intersertal brown mass.

Contact metamorphism.—Where the small dike-like mass of basalt breaks through the Pinal schists on Manitou Mountain, the latter rocks are transformed near the contact into a hard, reddish-brown, partly brecciated material, which resembles a baked quartzite rather than the usual schist. Under the microscope the metamorphosed rock is seen to be made up of irregular dark bands, consisting of plagioclase and quartz rather obscurely crystallized and crowded with microscopic particles of some dark pigment, alternating with clear bands consisting chiefly of quartz. The quartz grains, however, are rounded and embayed and are held in a web of brownish microlitic glass. This glass is apparently the result of partial fusion or of the corrosive action of the basaltic magma, acting along the surfaces where the original allotriomorphic quartz grains came in contact with each other. The process has attacked the grains from their peripheries and has rounded and embayed their outlines. A similar alteration has been effected by the basaltic magma on numerous inclusions of a light gray fine-grained granitic rock. Their sections show that these inclusions are usually enveloped in a film of pale-brown glass, which has also penetrated the inclusion interstitially for some distance from the actual contact.

Age.—North of Gold Gulch the small mass of basalt on the ridge top rests upon dacite, and is therefore younger. The main flow, between Gold Gulch and Manitou Mountain, rests upon and is in turn overlain by the Gila conglomerate. It is accordingly of the same age as the latter formation and may be provisionally referred to the early Pleistocene. Flows of basalt are mentioned by Gilbert, in the citation on page 47 of this report, as occurring in similar positions within the Gila conglomerate in the tributary valleys of the upper Gila. The age of the basalt just north of Gold Gulch, at the edge of the quadrangle is, as previously indicated, somewhat doubtful, but is provisionally considered as Pleistocene. Fully as uncertain is the age of the Pinal ranch mass and of the little body cutting the Hog ranch dike of granite-porphyry. These are included with the Pleistocene basalt merely on the ground of petrographical similarity. They may, however, be older.

FAULTS.

IMPORTANCE OF FAULTING IN THE DEVELOPMENT OF THE GEOLOGICAL STRUCTURE OF THE REGION.

The preceding pages contain a description of the rocks of the Globe quadrangle—the rough materials from which the forces of deformation and erosion have fashioned the existing geological structure and the visible configuration of the region. Before passing, however, to a consideration of the historical sequence and structural results of the geological processes which have wrought upon the rocks, it is desirable to devote some attention to the present expression and significance of that particular form of deformation which is preeminently characteristic of the district.

If one will stand upon the top of Webster Mountain and look northward or eastward over the confusedly hilly country spread out before him, he will be struck with the apparent chaotic distribution of the various rocks, as indicated by their respective and characteristic tints in the landscape. Here and there patches of limestone gleam white through the thin screen of scanty vegetation, while areas of quartzite are indicated by a reddish color, and masses of diabase by a dull olive tint. The beds show no trace of folding, and the eye seeks in vain for any persistent or regular structure that may account for this rocky patchwork. A similar view is obtained on looking southeast from the steep southeastern slope of the Pinal Mountains over the region just outside of the bounds of the quadrangle. Here, however, the structure has more regularity and the manifold repetition of beds of white limestone overlying reddish quartzites, all dipping gently to the southwest, is at once suggestive of faulting.

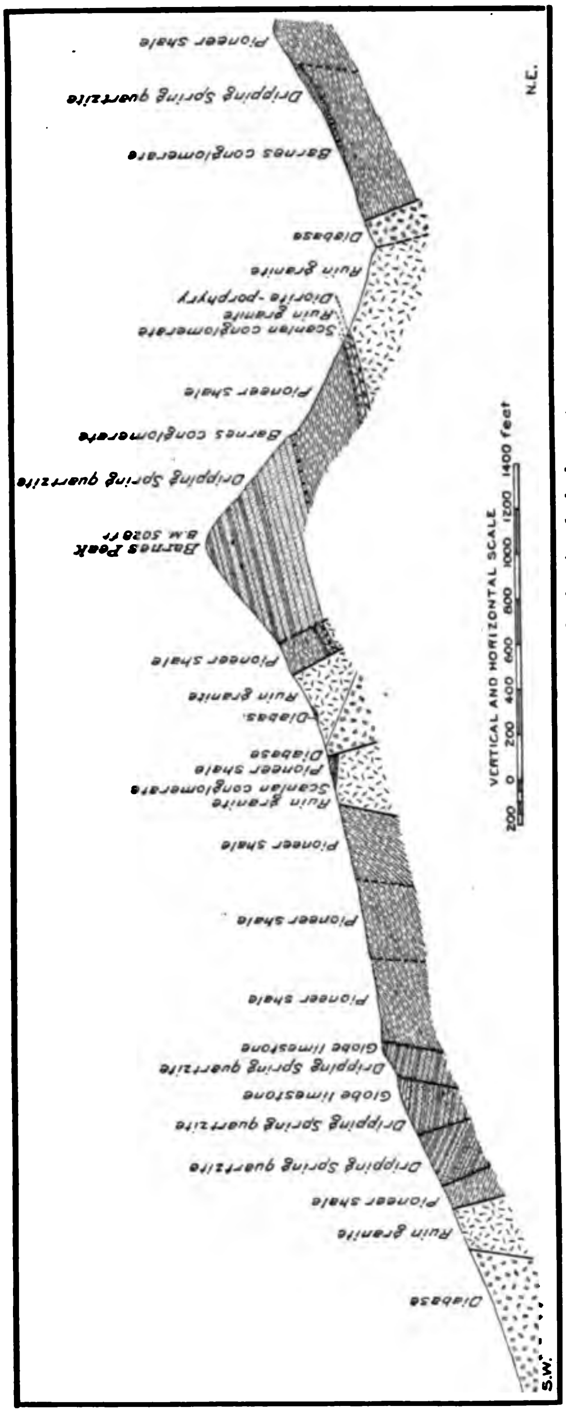


FIG. 5.—Geological section through Barnes Peak, showing faulted structure.

That this suggestion is in fact the clue to the dominant structure of all that part of the quadrangle in which the Apache group and Globe limestone are represented, becomes evident upon closer study. In traversing this faulted region one steps with bewildering frequency from quartzite to limestone, granite or diabase, the line of separation being often clearly defined by a fault breccia forming a bold outcrop (Pl. XVIII, *A*) that may be followed over the country for miles. Probably few equal areas of the earth's surface have been so thoroughly dislocated by an irregular network of normal faults, and at the same time exhibit so clearly the details of the fracturing. A rather inadequate conception of the extent of this regional shattering may be had from the geological maps (Pls. I and XV), from the generalized geological sections of Pls. II and XVI and from the more detailed but comparatively simple sections of figs. 5 and 6. The faults there

A. OUTCROP OF QUARTZITE FAULT BRECCIA ON PINAL CREEK, ABOUT 4 MILES NORTH OF GLOBE.

B. OUTCROP OF FAULT BRECCIA BETWEEN LIMESTONE AND DIABASE, ON NORTH SIDE OF BIG JOHNNIE GULCH.

shown, however, are merely those which attain some structural importance, and the numerous little fault blocks that they bound are themselves cut by faults far too many and too closely spaced for representation. For a considerable part of the northwestern portion of the quadrangle the term regional brecciation perhaps most aptly expresses the actual conditions there found.

Probably the majority of the faults have throws of less than 100 feet, and their marked influence upon the general structure of the region is dependent, as a rule, rather upon their enormous number than upon great individual displacement. In spite of much variety in strike and hade, the general result of the faulting has been to drop by successive steps toward the northeast, beds having a general southwesterly dip, the throws of the faults being such as to offset, in the main, the effect of the dip which would otherwise be effective in rapidly carrying the strata above or below the present erosion surface of the quadrangle. It is due to these faults of generally moderate displacement that the Globe limestone, for example, retaining in most cases a southwesterly dip of from 20 to 40 degrees, is scattered broadcast in small areas over the quadrangle.

Much of the structure of the region is partly dependent upon faults which no longer appear as distinct dislocations, and are not represented by fault lines on the geological maps (Pls. I and XV). These are generally northwesterly or northeasterly fractures which immediately preceded or accompanied the great diabase intrusion, and which, from their close con-

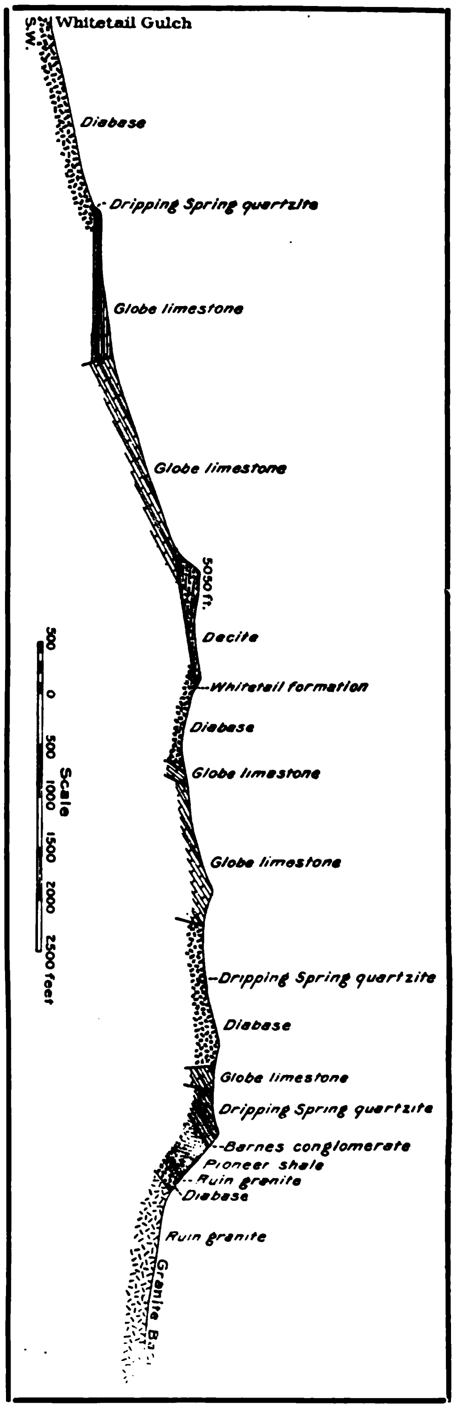


Fig. 6.—Geological section from Granite Basin to Whitetail Gulch, along northeast-southwest ridge. The line of the section passes half a mile northwest of Webster Mountain.

nection with this event, may be conveniently distinguished as intrusion faults. They became at the time of eruption channels for dike-like connections between the sills, and were important factors in determining the form of the molten mesh in which the blocks of strata were inclosed. Most of the surfaces of dislocation were transformed to eruptive contacts, with which, however, planes of later faulting frequently in part coincide, as in the case of the Old Dominion fissure described on pages 136 to 139.

In most regions of diversified topography underlain by stratified rocks the dominant structures are due to folding, modified to a greater or less degree by faulting. In the Globe quadrangle, on the other hand, the structure, where not traceable directly to the effect of igneous intrusions, is the result of faulting, while folds are either entirely absent or represented by an occasional gentle and structurally unimportant buckling of the strata occurring in some fault block.

DISTRIBUTION OF THE FAULTS.

Upon referring to the geological map (Pl. I) it may be seen that the faults are very much more numerous in the northern than the southern half of the quadrangle. It is further apparent that the crystalline schistose and granitic complex forming the mass of the Pinal Mountains is nearly free from dislocations, while the latter are particularly abundant wherever the Apache group, Globe limestone and diabase are the prevailing rocks. To some slight degree this difference is probably exaggerated, as faults in the granitic and schistose terranes are structurally inconspicuous and may be overlooked in mapping, while even small faults may effect striking results in traversing beds of quartzite and limestone. Such slight exaggerations, however, can hardly detract from the great actual contrast presented on the one hand by the relatively simple structure of the Pinal Mountains, with their batholithic granitic masses irregularly invading the schists, and on the other by the complex dislocation of the northern half of the quadrangle.

No faults are shown within the large areas of Gila conglomerate, such as the Pinal Creek and Mineral Creek areas. This is chiefly due to the fact that the more important faults antedate the deposition of this formation. It is undoubtedly cut, however, by faults of later age, but it is impossible to trace these for any considerable distance in material of this character. It is almost equally impracticable to detect or follow faults on the surface when dacite forms both walls of the fissure, and this fact is probably in part responsible for the paucity of the faults mapped within dacite areas.

THE EVIDENCE OF FAULTING.

With probably not more than a dozen exceptions, the several hundred faults shown on the map (Pl. I) were actually traced on the surface, usually by the aid of a fault breccia. Such a breccia is invariably present where quartzite of the Apache group forms one or both walls of the fissure. It is commonly made up of angular fragments of quartzite, with occasionally rounded pebbles dragged in from some conglomerate bed dislocated by the fault, the whole being embedded in a more or less rusty matrix of siliceous detritus, and often cemented by oxide of iron. Sometimes fragments of diabase, schist, or other rocks traversed by the fault are mingled with the quartzite, and in a few cases, where faults cut Pinal schists, the breccias are composed entirely of fragments of the latter rock. But by far the greater number of the fault breccias in the region consists chiefly of crushed quartzite.

These quartzitic breccias are frequently so indurated as to be more resistant than the rocks on either side, and they then outcrop boldly as ragged walls stretching across the country. Examples of such indurated breccias are abundant over the northern half of the quadrangle. One forms a conspicuous crag by the roadside about 4 miles northwest of Globe (Pl. XVIII, *A*). Another (Pl. XVIII, *B*) separates limestone from diabase on the northwest side of Big Johnnie Gulch (see Pl. XV). Still others stand out prominently south of the trail from Granite Basin to Horrell's west ranch, and notable breccias of schist fragments, showing considerable alteration and mineralization, occur on Pinto Creek near the mouth of Cottonwood Gulch.

Frequently the faults bring into juxtaposition rocks unequal in their resistance to disintegration, and a scarp of more or less topographical prominence results from differential erosion. The region affords many examples of such scarps, one of the best being shown in Pl. XIX, where hard quartzites of the Apache group are normally faulted against crumbling Ruin granite. Such scarps are of purely erosional origin depending upon the relative hardness of the rocks and not upon the throw of the fault.

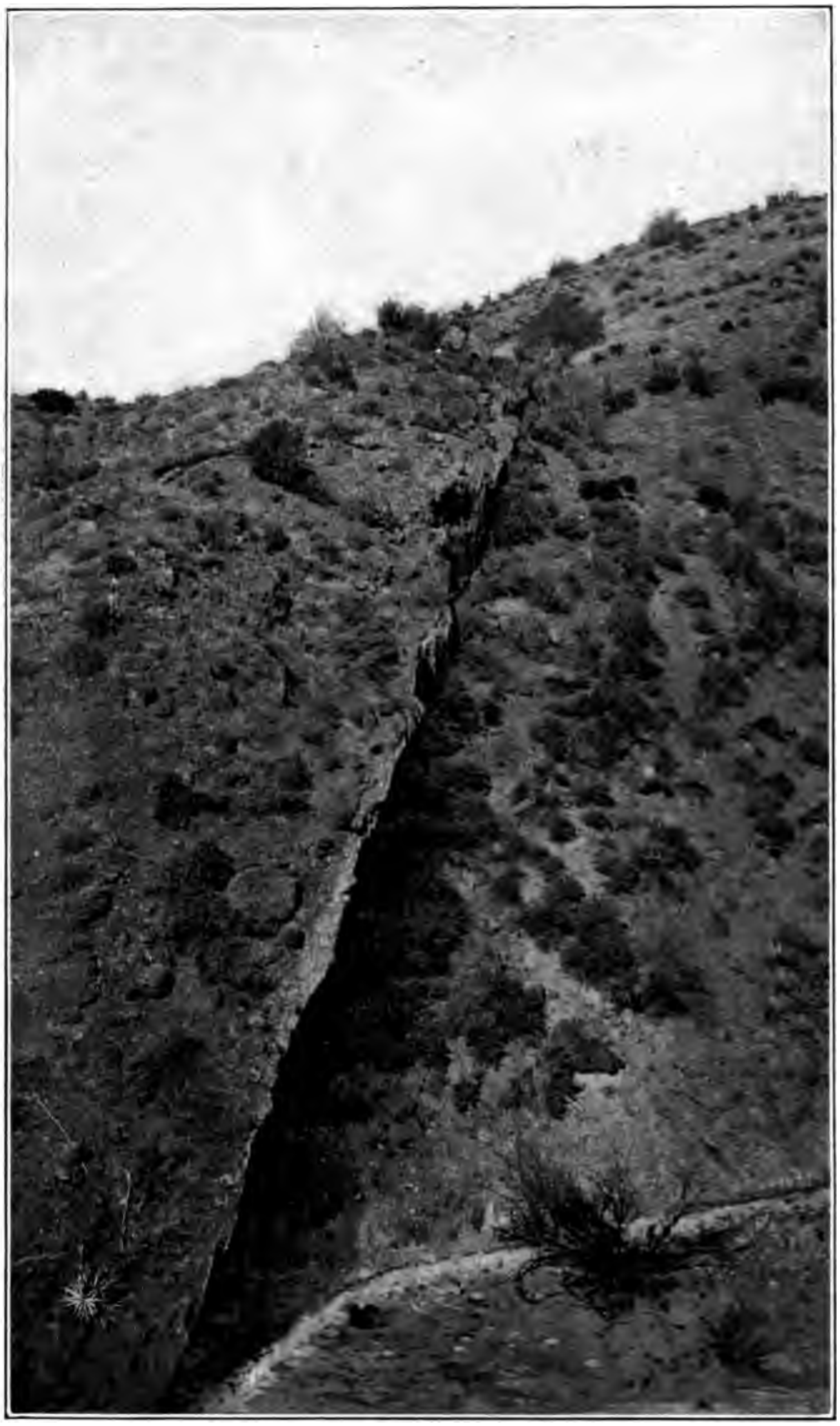
Where pronounced topographical expression fails, there is still usually no great difficulty in actually tracing the course of a given fault over a country where the character and attitude of the rock under foot is rarely in doubt, and where the outcrop of the fault plane is confined within the limits of the single step that usually suffices to pass from one rock to another. Without such clear exposures it would be impossible to express the complex structure other than by the crudest and most inaccurate generalizations. The chief embarrassment, as a rule, lies not in finding the evidence of dislocation, but in determining which one of many faults shall be mapped as structually the most significant where it is impossible to show them all, and, amid the general shattering, in identifying throughout its course the particular fault originally selected.

Faults wholly in diabase or limestone are usually not conspicuous. Their courses in the former rock are often marked by zones of brecciation which are commonly stained black by oxide of manganese and sometimes mineralized with salts of copper. The passage of a fault through limestone may produce considerable brecciation, which, however, is likely to be so healed by recrystallization of the calcite as to be detected with some difficulty, as in the case of the Old Dominion fault north of the Hoosier shaft (Pl. XV).

While only a very small proportion of the faults are perceptibly mineralized, many of them have been superficially prospected, and the study of some of the more obscure dislocations of the region is indebted to that remarkable instinct which guides the impartial pick of the prospector to the discovery of fissures, irrespective of the wealth or poverty of their mineralization.

The evidence for the intrusion faults associated with the diabase eruption is of a more general character than that of the later faults directly traceable on the surface. In a few instances the diabase can be observed in undisturbed eruptive contact with a regular surface of dislocation cutting across the bedding. But in other cases later movement has taken place along this contact, and the original character of the latter is inferred from the petrography of the diabase near the fissure and from the demonstrable inadequacy of the later faulting to account for all of the continuous structures. Taking for example, the Old Dominion fault (fig. 7), we find (p. 136) that the diabase of the foot wall exhibits the texture characteristic of this rock near its original intrusive contacts. Furthermore the existence of an included block of limestone in the diabase of the foot wall is unexplainable if the relation of the diabase foot wall to the limestone and quartzite hanging wall be supposed wholly due to faulting of later date than the solidification of the eruptive rock. Lastly, even if the limestone in the foot wall be disregarded, the general geological evidence indicates that the faulting subsequent to the diabase intrusion has been of too moderate displacement to wholly account for the relative position of diabase foot wall and limestone hanging wall. Thus the dacite in the upper workings of the Old Dominion mine shows a throw of less than 100 feet, a displacement wholly insufficient to explain the juxtaposition of diabase and limestone observed in the lower levels.

Still further evidence for these intrusion faults is afforded by the general structure of the region as expressed in the geological maps and sections (Pls. I, II, XV, and XVI). It is apparent from these that extensive dislocation of the beds must have preceded or accompanied the diabase intrusion and prepared the blocks of strata for their erratic dispersal and rearrangement by the mass of molten magma forced into the shattered fabric.



FAULT PLANE DEVELOPED INTO A SCARP BY EROSION.

Rock on the left (hanging wall) is quartzite, that on the right (foot wall) is granite. The fault is normal.

DIRECTIONS AND CHARACTER OF THE FAULTING.

The dominant faults of the Globe quadrangle fall into two groups, (1) those having a generally northeast-southwest trend, and (2) those striking approximately northwest and southeast The dislocations of the first group dominate the structure of that portion of the Globe Hills lying just north of Globe and are conspicuous in the vicinity of Black Warrior and Lost Gulch. These faults have dips ranging from 55° to 90°, the greater number being inclined about 75° to the horizontal. Northwesterly dips are about as frequent as southeasterly, and as the throw of the faults is apparently always normal, these dislocations have resulted in dropping downward-pointing wedges of geologically higher rocks between upward-pointing wedges of lower rocks (trough faulting). Thus, on the south slope of Buffalo Ridge (Pl. XV) little areas of Globe limestone are inlaid, as it were, in the quartzites of the Apache group, between the two branches of the Buffalo fissure. The Lost Gulch monzonite is a fault block separated on the northwest and southeast from geologically higher rocks that have been dropped against it by faults of this group.

The fissures of the second group dominate the structure northwest of a line passing through Sleeping Beauty Peak and the Continental mine, and in the extreme northeast corner of the quadrangle. The usual dip of these faults is about 75° and may be either to the northeast or southwest. West of Pinal Creek, the net result of the many displacements has been a general dropping of the beds toward the northeast (step faulting). In the northeast corner of the quadrangle, however, the faulting already begins to partake of the character of that along the western face of the Apache Mountains, resulting in a general elevation of the beds toward the northeast.

Although faults belonging to the two groups just recognized have effected the most conspicuous structural results, they are associated with countless other fissures running in all directions and adding greatly to the complexity of the fault network. It has proved impossible to reduce these generally subordinate fractures to distinct groups or systems, and when it is remembered that for every dislocation shown upon the map there are several others unrepresented, and that the faults are of different ages, the reason for failure is apparent. The region has not been dissected with mathematical precision along determined lines, but has been shattered by complex geological forces to an extent that is only less defiant of analysis than is a pane of shivered glass.

Among the many hundreds of faults occurring within the quadrangle are a number in which the character of the relative movement is not clearly shown, either because the hade of the fault is unknown or because the original geological horizons of the rocks adjacent to the fissure are in doubt. The majority of the faults, however, are clearly normal, while indubitable cases of reversed or thrust faulting are unknown.

AGE OF THE FAULTS.

The earliest dislocations distinctly recognizable in the structure of the Globe quadrangle are the intrusion faults associated with the post-Carboniferous (Mesozoic?) intrusion of diabase. From the close of this period of revolutionary eruptive activity to the probably Tertiary outbursts of dacitic lava one process only—that of erosion—has left a fairly legible record. It is believed, however, that important faulting also took place during this interval, and that some of the fissures which do not at present cut the dacite, and particularly those showing mineralization, are actually of predacitic age. The evidence for this belief is drawn from observations tending to show that the original sulphide ore of the district is older than the dacite, as will be more fully shown in the sequel. The last great faulting of the region, that tremendous shattering which finds its best expression in the northwestern portion of the quadrangle (Pl. I), followed the dacitic eruptions, and involved their lava in the final structure of the resulting geological mosaic. The date of this fissuring which blocked out the existing structure of the country is not definitely known. As it occurred after the dacite eruptions and before the accumulation of the Gila conglomerate, it may provisionally and tentatively be referred to the Neocene. Its results can not always be clearly distinguished from the earlier faulting that followed the diabase intrusions and preceded the eruption of dacite. Faults once initiated have usually remained planes of weakness along which there has been a revival of movement with each successive period of dislocation.

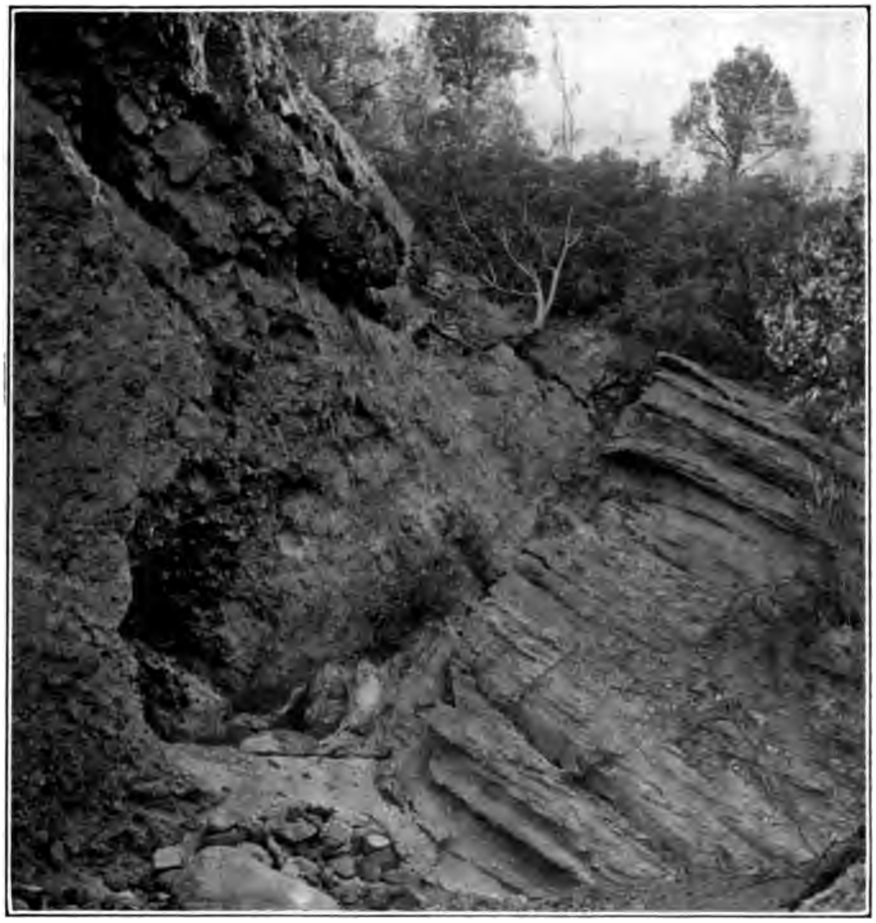
Numerous normal faults, usually of small throw (Pl. XX), cut the Gila conglomerate and indicate the continuance of faulting into the Pleistocene, while the presence of soft gouges and unconsolidated breccias in some of the Neocene (?) faults show that displacement is probably even yet in progress.

Although it has been ascertained that the faults of the region are of various ages, it has not been possible to discover that those of any period were distinguished by the possession of peculiar trends.

GEOLOGICAL SIGNIFICANCE AND ORIGIN OF THE FAULTING.

As the earliest recorded faulting was apparently closely followed by the intrusion of diabase, the circumstances under which the fracturing took place and the forces to which it was due are somewhat obscure. It is clear that rather thick and brittle beds were much fissured and that the diabase, instead of being confined to regular and persistent sills, filled the fractures and in many cases greatly

A.



B.

TYPICAL FAULTS IN GILA CONGLOMERATE.

A, Alice Gulch near Old Dominion mine; *B*, near Black Warrior.

displaced the severed blocks of strata. The number of the dislocations and the comparatively small size of the fault blocks indicate that the beds did not at the time of their rupture lie under great load, and the facility with which the blocks were shifted by the magma is evidence that the intrusion also took place under no great superincumbent mass. The entire absence from the region of remnants of any rocks that might have overlain the Globe limestone when it and older rocks underwent such extensive deformation affords additional ground for the conclusion that the faulting and intrusion must have taken place within a very moderate distance of the surface as it was at that time.

The present geological structure is such as to suggest that this earlier faulting was generally normal in character, but whether the original dislocation was due directly to the intrusive force of the diabase or to the earlier and perhaps independent stresses has not been determined.

The postdiabasic and predacitic faulting, with which is associated the primary mineralization of the quadrangle, can not as a rule be satisfactorily distinguished on structural grounds from the postdacitic faulting, partly because the latter, as in the Old Dominion fault, revived older dislocations.

In an attempt to deduce from the character of the postdacitic faulting the circumstances under which it took place and the forces to which it was due, the fact that an overwhelming proportion of the faults are demonstrably normal is of prime importance. Normal faulting implies horizontal extension and is incompatible with regional tangential compression, a conclusion which is strongly reenforced by the absence of folding in the stratified rocks. The fact that beds when normally faulted tend to occupy a greater area than before their dislocation can not, however, be taken as evidence that tangential tension has been a cause of the fracturing. The existence of such a stress is geologically improbable, and even if set up it would be relieved by the first fracture formed. The only conceivable stresses that can offer any satisfactory explanation of the faulting of the Globe region are those acting in directions more nearly vertical than horizontal, such as would result from differential elevations or subsidences over the area. The behavior of the rocks may be likened to that of a large and thick sheet of plate glass lying horizontally upon an uneven surface and fissuring under its own weight in consequence of unequal support. The generally rather thick-bedded and brittle rocks of the quadrangle are, however, far more easily and thoroughly fissured by geological processes than would be the relatively insignificant mass of glass by the feeble stresses of the suggested experiment.

It is certain that the rocks of the quadrangle when broken by the postdacitic (Neocene?) faulting were practically free from load other than their own mass. It is inconceivable in the light of the geological history of the district that any considerable thickness of rock should have accumulated in Tertiary time above the dacite and then have been completely removed, leaving no trace of its former presence. When the faulting occurred, dacite was probably the surface rock over such considerable portion of the region as did not stand too high to be buried beneath the lava at the time of eruption. It was certainly the youngest rock occurring in any considerable mass within the quadrangle. Erosion since the period of dislocation has undoubtedly reduced the thickness of the dacite. But such reduction does not affect the general force of the statement that when the postdacite faulting occurred, the rocks involved were, with the exception of the Gila conglomerate and Pleistocene basalt, those now exposed, and that the phenomena observed are those associated with rock fracturing taking place close to the surface and therefore under little or no load.

The results as described in preceding pages for the northern half of the quadrangle are such as might be expected under the conditions just outlined—a shattered, brecciated region, cut by innumerable small normal faults showing varying local regularity in strike, which is more or less masked by the apparently haphazard trend of the countless smaller fractures. It is not known why the main crystalline massif of the Pinal Mountains escaped the minute dissection of the rest of the area. It is possible that its lithological character and the relation of the batholithic masses of granitic rocks to the schists presented elements of strength lacking in the surrounding areas where stratified rocks and diabase prevail, and that it consequently moved as a unit in the general readjustment of the region by faulting.

The causes of the postdacite and postdiabase faultings are deep seated and inscrutable. It is suggestive that here, as in the San Juan region of Colorado,[a] the later fissuring followed an extensive transfer of volcanic material from its subterranean source to the surface. It is probable that there is a more or less direct connection between such volcanic paroxysms and the subsequent fissuring. The earlier, structurally less conspicuous, but economically more important, postdiabase dislocations were also preceded by great eruptive activity, and it is reasonable to regard this faulting also as a phase of regional readjustment after the widespread disturbances effected by the intrusion of the diabase.

The latest faulting of the Globe district, manifested by slips along earlier fault planes and minor dislocations of the Gila conglomerate, are regarded merely as indications that the shattered rock masses of the region are still approaching by slow steps the elusive goal of final equilibrium, which was not attained by the vigorous movements of the postdacitic fissuring.

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[a] See Bull. U. S. Geol. Survey No. 182, 1901, p. 66.

GEOLOGICAL HISTORY.

Long before Cambrian time the Globe region was part of a sea bottom upon which were accumulating fine grits and silts, probably derived from granitic rocks. The source of these sediments is unknown, and no trace of the ancient rocky floor upon which they were laid down is now visible. In the course of time sedimentation ceased, the beds were folded and compressed by forces acting in a generally northwest-southeast direction, were intruded by great masses of quartz-mica-diorite (the Madera diorite), and underwent crystalline metamorphism into the Pinal schists. Later intrusions of granite, granitite, and monzonite followed, and at the close of this period of plutonic eruptive activity the region had risen above the sea and become mountainous. A new physiographic cycle was thus initiated, which was probably well under way, however, before the constructive processes that have just been outlined were concluded. Before the rocks attained their final elevation erosion was vigorously at work, and, upon becoming ascendant, began the actual reduction of the mountainous topography, carrying it successively through the various intermediate stages of the geographical cycle to the final one of the nearly featureless worn-down plain of old age—a peneplain.

So much, in brief, of pre-Cambrian history is decipherable from the character, structure, and texture of the older rocks. The cycle was run, and the initiation of Cambrian time was marked by subsidence and a fresh advance of the sea over what had so long been dry land. The sea as it swept over the peneplain found it littered in part with fragments of quartz weathered out from veins in the schists and granitic rocks, and with smaller particles of feldspar and quartz derived from the disintegration of the granitic masses. The existence of particles of feldspar, which have remained fairly fresh to the present time, appears to afford some indication that the Cambrian climate was not conducive to soil formation or to abundant vegetation. These materials were slightly reworked by the waves into the Scanlan conglomerate, the remnants of which are now found resting usually upon the weathered and reddened surface of the Madera diorite and the granites, sometimes separated from the sound rock by several feet of pre-Cambrian granitic saprolite (disintegrated rock in place). The Scanlan conglomerate, or its equivalent, covered the Pinal schists as well as the plutonic rocks, but the former relationship is visible only in a few fragmentary exposures west of Black Warrior, where the Scanlan conglomerate is represented by a breccia consisting chiefly of glassy quartz fragments embedded in a matrix composed of smaller particles of schist. It appears that the region was submerged too rapidly to permit any considerable rounding of the pebbles by wave action, or to allow much transportation of material by littoral currents, both of which processes are favored by stability of shore line. The lack of such evidence of long-continued shore action shows that the floor upon which the Cambrian sediments were deposited was in the main due to subaërial erosion and not to marine planation.

Either there were valleys in the old peneplain as much as 200 feet in depth, or the region subsided unevenly to an equal extent, for in the Apache Mountains the interval between the pre-Cambrian peneplain and the base of the Pioneer shale, elsewhere occupied by from 1 to 6 feet of Scanlan conglomerate, is filled by some 200 feet of hard and varyingly arkose quartzite.

The Pioneer shale, overlying the Scanlan conglomerate and the lower quartzites of the Apache Mountains, records the accumulation of sandy silt in waters so shallow that the mud sometimes lay bare and was dried and cracked by the sun. The material of these sediments was in part feldspathic and probably derived from an adjacent land mass, composed largely of granitoid rocks similar to those occurring in the Pinal Mountains. While there is no direct proof that the rocks of these mountains themselves were reduced to the general level of the peneplain and covered by the Cambrian sediments, yet it seems most probable that such was the case, and that they owe their present elevation and the stripping of their Paleozoic cover to later movements and to erosion. It is not likely that there existed any such sharp and local exception to the general unevenness of what must have been at one time an extensive peneplain.

The deposition of the Pioneer shale was succeeded by that of the Barnes conglomerate. The origin of this conglomerate, which, with its well-rounded pebbles composed largely of quartzite, succeeds so strikingly the reddish sandy shales and quartzites beneath it, presents questions to which the region investigated returns no answer. Without any apparent unconformity, the quiet deposition of fine silt was succeeded by the laying down of fairly coarse conglomerate, bearing evidence of continued wave or current action, and plainly derived from earlier (Algonkian?) sedimentary deposits concerning which the Globe quadrangle furnishes no knowledge. The matrix of the Barnes conglomerate, however, still shows abundant feldspathic detritus, such as might have been supplied by a neighboring unsubmerged area of the pre-Cambrian granitic rocks.

Succeeding the Barnes conglomerate came the accumulation of quartzose sands, now represented by the Dripping Spring quartzite. These appear to have been laid down in somewhat deeper water than the preceding beds, although the occurrence of conglomerates and grits in the upper part of the formation suggests a return of littoral conditions at the close of the Cambrian.

The geological record of the limited region studied is silent as regards Silurian time. No strata of this age have been identified, nor, on the other hand, has any unconformity been certainly detected between the Cambrian and the Devonian, to account for their apparent absence. Such field evidence as could be obtained bearing upon this point is inconclusive. Inasmuch as Walcott has shown that an actual unconformity, rarely discernible, exists between the Cambrian and Devonian beds in the Grand Canyon, it is possible that a similar usually invisible stratigraphical break may be present in the Globe district. If so, the region was elevated with little or no deformation of the beds, and remained dry land throughout the Silurian. It is conceivable, however, that the absence of the Silurian strata is not due to emergence of the sea bottom, but to a cutting off of the supply of sedimentary material, either by a depression so great as to carry this part of the sea bottom beyond the reach of land waste, or by a reduction to approximate base-level of the area supplying the sediments. In such an event the Silurian might be practically unrepresented and yet there would be no real unconformity.

Passing to the Devonian, we find some ground for the suggestions last made in the fact that arenaceous deposits are here almost absent and limestones predominate. At the base of the latter are frequently encountered calcareous grits, forming an apparent transition from the underlying quartzites to the nearly pure limestones. It has been found impossible to believe these to be other than actual transitional beds in a conformable sequence. Yet they are not always present, and the occurrence of a little quartzitic breccia observed at a single point at the base of the Globe limestone north of Globe (see p. 40) enforces the suggestion of a possible unconformity.

From the Devonian to the Upper Carboniferous the region was covered by a sea of some depth abounding in marine life and depositing abundant limestone. Although no characteristic Lower Carboniferous fauna was found, rocks of that period may be present, and the Globe limestone as a whole contains no visible unconformities. From time to time there were slight incursions of sediment, and in a few instances bands of siliceous conglomerate were intercalated within the limestones. The mass of these is unimportant, but they are significant in showing that this part of the Devonian and Carboniferous sea was probably neither very deep nor far distant from a land mass.

The Upper Carboniferous limestone is the latest Paleozoic deposit of which the region preserves any record. If marine conditions continued into the Permian the deposits of that period must have been wholly removed before the strata were broken up and invaded by diabase. Had Permian or later beds been involved in that structural revolution some traces of them would probably have been preserved in the resulting intricate lithological mosaic.

There are no available means of determining whether or not the region became land and was eroded before the diabase intrusion. We know only that the latter event with its associated faulting occurred after the accumulation of the Globe limestone, and has left unmistakable record of its structural importance. The region was presumably elevated above sea level at the close of the Carboniferous and subjected to erosion. It was extensively dissected, probably in Mesozoic time, by numerous faults, which appear to have been normal in character, unusually of moderate throw, and to have had generally northwest-southeast and northeast-southwest trends. There is ground for supposing that the crystalline massif of the Pinal Mountains escaped much of the intensity of this as it did of a later period of faulting. Following or accompanying the dislocations an enormous quantity of molten diabase magma was intruded into the rocks of the region, particularly into those most cut by the faults. If present exposures can be taken as generally indicative of the original proportion of the diabase to the stratified rocks, it appears that the intruded rock fully equaled if it did not considerably exceed in volume the stratified rocks. As the latter were not fused at any point now exposed to observation, room for this great addition of material was effected by mechanical displacement. The dominant form taken by the diabase was that of the intrusive sheet or sill, and had the region not been shattered by faults these sills would probably have been fairly regular, resembling those occurring in the less faulted portions of the country just without the quadrangle, such, for example, as are well exposed in the canyon of Salt River just below its junction with Tonto Creek. As it was, however, the diabase not only forced its way between the beds as sills of varying thickness, but found in the region of greatest faulting the most favorable opportunity for expansion. It occupied the fault fissures and shoved the detached masses of ruptured strata bodily aside, separating them so that they became in many cases mere inclusions in a great mass of eruptive rock. All the observed phenomena connected with the faulting and intrusion, as well as the more general geological considerations outlined in preceding pages, indicate that these events took place comparatively near the surface. The contact metamorphism effected by the diabase is of the most insignificant character, while vesicular and aphanitic facies of the intrusive rock are common near original contacts. The manner in which the blocks of strata were displaced indicates that they were under no great load, and the great increase of volume resulting from the intrusion of the diabase must have produced considerable actual elevation of the surface over the Globe region. It would seem that with such active deformation and intrusion in progress at so slight a depth, at least some of the magma must have found its way to the surface and been erupted as basalt. Any such manifestation of volcanic activity as may have existed has, however, since been removed by erosion.

With the close of the diabase intrusion the region, having probably gained in elevation, was subjected to subaerial erosion. It is not unlikely that during the Mesozoic it underwent many unrecorded vicissitudes, and may have been covered by sediments that were afterwards stripped away. It is very probable, however, that normal faulting took place during this period, closely followed by ore deposition.

At a time which can not be definitely fixed, but which is provisionally considered as coinciding with the earlier part of the Tertiary, the region, characterized by a somewhat diversified topography, was apparently dry land and undergoing erosion. Although the topography was probably less rugged, the general conditions appear not to have been very greatly different from those of the present day. As shown by the accumulation of the Whitetail formation, coarse, rather angular detritus was washed down the slopes and deposited in the more open valleys or gulches.

It was this uneven surface that was in greater part buried by the probably early Tertiary eruptions of dacite. As the Whitetail formation occasionally shows rude stratification in its upper part and the massive dacite is frequently underlain by beds of tuff, it is probable that the quadrangle was at this time partly covered by transient bodies of water, possibly due to a disturbance of the drainage by orogenic movements immediately preceding the eruptions. As a result of the latter the whole of the quadrangle, with the possible exception of the Pinal Mountains and some of the foothills of the Apache Mountains, was covered with a flow of dacite, which in its greatest thickness probably exceeded a thousand feet.

Following closely after this volcanic activity came the great faulting to which is chiefly due the present structure and less directly the topography of the region. The nature of this faulting has already been described in pages 97 to 106. By it the northern half of the quadrangle was shattered to an extent but imperfectly shown by the great number of small fault blocks outlined upon the geological map (Pl. I). The southern half of the quadrangle, however, shows comparatively little dislocation, and it is evident that the crystalline massif of the Pinal Mountains moved as a unit and forms the largest fault block in the area. On the southeast this block is fairly well defined by a strong northeast-southwest fault that has dropped rocks of the Apache group and Globe formation, with intruded masses of diabase against the older Pinal schists and Madera diorite lying to the northwest. Toward the south and southeast the Pinal Mountain block apparently extends beyond the bounds of the quadrangle. On the northwest the passage into the region of intense faulting is somewhat indefinite, and no single fault was found marking a simple boundary between the Pinal fault block and the shattered rocks to the northwest of it. On the northeast the Pinal Creek area of the Gila conglomerate effectually conceals the structural boundary separating the Pinal fault block from the minutely dislocated Globe Hills. The strata of these hills dip generally to the southwest beneath the Gila formation. They reappear again on the back of the Pinal fault block near Pioneer, and here also have a persistent southwesterly dip. If the portions of the beds removed from this block by erosion were restored they would lap up over the southwestern slope of the Pinal Mountains and form a scarp along the crest of that range overlooking the Globe Valley and the very much lower fragments of the same strata in the Globe Hills on the far side of the gravel-filled depression. It is not impossible that the Apache and Globe beds and the overlying dacite formed a complex anticline over the crystalline core of the Pinal Mountains and a syncline beneath what is now the Globe Valley. But as there are here no discoverable traces of structure so wholly lacking in representation in other parts of the region, it is fair to conclude that the observed tectonic relations have resulted either from a single generally northwest-southeast fault of over 6,000 feet maximum throw, or from a zone of faults of like trend. In either case the depth of the Gila conglomerate effectually prevents any study of these faults at the surface. The fissure which cuts off the Lost Gulch monzonite on the northeast and apparently passes beneath the Gila conglomerate to the southeast has a throw of the kind required in members of the hypothetical fault zone suggested.

The crystalline massif of the Pinal Mountains is thus regarded as an eroded fault block, uplifted along its northeastern edge, and, consequently, tilted to the southwest. It is possible that the concealed fault or fault zone along the northeastern front of the range, of which the maximum throw can scarcely be less than 6,000 feet, is only in part due to postdacitic dislocation, and that the initial displacement dates from the episode of intrusion faulting connected with the diabase eruption, or that of the postdiabase fissuring.

In the absence of any satisfactory evidence for connecting with the recognized geological epochs the events which took place in this district after the close of the Carboniferous, the postdacitic faulting is rather arbitrarily considered as ending the Tertiary. The provisional nature of this and other post-Carboniferous correlations in this region should not be forgotten. They may be considerably modified when the geological work in the Globe quadrangle is supplemented and extended by the study of a broader area. The divisions recognized appear to be distinct chapters in the local physical history. They may not, however, be correctly inserted in the larger volume of the geological story of the earth.

The Pleistocene was opened by a vigorous erosion of the complex lithological mosaic resulting from the superposition of the postdacitic shattering upon in the northern half of the quadrangle. These features depend primarily upon the geological structure whose development has been traced in the preceding pages, and secondarily upon the erosion of the present cycle. The elevation of the Pinal block, while it led to the rapid stripping off of the Paleozoic and younger rocks, exposed to the present erosion the little fissured and generally resistant foundation of crystalline schists and granitic batholiths. Thus the Pinal Mountains are the result of an original uplift which subsequent erosion has greatly lowered and sculptured, but, checked by the highly metamorphosed schists, has been unable to degrade to the general level of the surrounding country. The topography of the range is still characterized by the steepness and sharpness of form associated with physiographic youthfulness.

The Globe Valley, on the other hand, probably originated as the downthrown region lying northeast of the Pinal uplift, the result of such downthrow being to form a structural depression floored with shattered Paleozoic sediments, diabase, and dacite. How far erosion was able to modify this floor before it was buried beneath the Gila formation is of course unknown. The existing topography of the valley exhibits a stage of mature dissection of the fluviatile deposits that fill it. As the principal intermittent streams issue from the Pinal Range, they tend to retain the axial stream, Pinal Creek, close to the base of the Globe Hills. Near the northern edge of the quadrangle, however, the conditions are reversed, and the influence of the stronger drainage from the Apache Mountains, with its more extensive deposition of detritus, is seen in the crowding of Pinal Creek over toward the hills west of Gerald's ranch.

The topography of the northern half of the quadrangle is closely related in its irregularity to the rock masses that underlie it. It is such as might be expected from the erosion of a region having planless heterogeneity of structure. The drainage plan of such a tract records minute adjustments to conditions of great local diversity. Each little fault block by its materials and position has influenced the topography. Areas of granite or diabase tend to become valleys or basins, while quartzite and limestone form ridges or peaks.

THE ORE DEPOSITS.

HISTORY OF MINING DEVELOPMENT.

Prior to the year 1874 the desert isolation of the mountains of central Arizona and the predatory Apaches who lurked within these rocky fastnesses appear to have been obstacles from which even the proverbially hardy prospectors shrank. But in that year a temporary subjection of the Indians opened the way to the bolder spirits, and a party of prospectors, having crossed the Pinal Mountains from the west, located the Globe claim, now part of what is generally known as the Old Dominion mine. The Silver King mine, lying about 19 miles south-southwest from the present town of Globe, was located by members of this same party as they were returning to Florence. Other discoveries rapidly followed and small settlements sprang up at various points. One of the first of these, known as Ramboz Camp, was founded by Henry Ramboz in 1875. The ruins of this camp and some neglected graves of its pioneers may be seen about 4 miles northeast of Globe, at the foot of Ramboz Peak. It was the base whence active prospecting was carried on in the Globe Hills during the seventies, when some mines, such as the Fame, Centennial, and Rescue, were opened and produced silver ore in commercial quantities. Although the Globe claim, destined afterwards to become the greatest copper producer in the district, was the earliest location, it attracted but little attention for several years, owing to the greater interest aroused by silver ores and the success which was already attending their exploitation in the Silver King mine.

Other settlements or camps sprang into existence about the same time as that at Ramboz. Among these were Cottonwood Springs, Richmond Basin, Watsonville, and McMillanville. Richmond Basin, situated on the southwest slope of the Apache Mountains, first came into notice through the nuggets of native silver which were found in the superficial wash and decomposed rock forming the floor of the little depression whence the name of the settlement was partly derived. Shafts were sunk, that of the McMorris mine reaching a depth of 800 feet and producing high-grade silver ore up to 1882, when work ceased. Most of this ore was treated in a mill at Wheatfields, on Pinal Creek, something over 12 miles northwest of Globe, although in 1878 some was apparently worked in the old Miami mill, 4 miles from Globe, at the northern end of Miami Flat. The total yield has been variously reported as from $300,000 to $647,574.85. The Nugget mine, about 2 miles southwest of Richmond Basin, was also a prominent mine of these early days, and had a small stamp-mill east of Gerald's ranch and 7 miles due north of Globe.

McMillanville, in the Apache Mountains, about 20 miles from Globe, was a well-known and active camp during the later seventies, owing largely to the operation of the Stonewall Jackson mine. Rich bunches of ore carrying native silver were found in this mine in 1878 and 1879, and a 5-stamp mill was erected at McMillanville in the latter year.

Throughout this period and up to about 1884 the Silver King continued productive and reached a depth of over 700 feet. Like several other of the silver mines mentioned in this historical sketch, it lies outside of the bounds of the Globe quadrangle, although within what may be broadly considered as the Globe region.

Some time prior to 1878 the principal settlement of the district was transferred from Ramboz to Globe, the choice of the latter situation being probably determined by the more plentiful water supply afforded by the bed of Pinal Creek and the better position of the latter place as a general distributing point for the whole region. A newspaper, the Arizona Silver Belt, was started about this time, and from its files, extending from May 2, 1878, to January, 1902, many of the facts of the present sketch were gleaned.

During 1878 and 1879 the raids of the Apaches under Geronimo and Victorio kept the miners in a state of constant anxiety. But, although isolated prospectors sometimes fell victims to the savages, the latter never ventured to attack the settlement of Globe.

In 1880 the Globe region was producing silver from several small mines within and adjacent to the area embraced by the present quadrangle. The most prominent properties at this time appear to have been the McMorris and Stonewall Jackson, the former being credited with a product of $84,370.58 for six months of the year. The Buffalo and Alice mines were also opened about this time for silver ore, and the Old Dominion (original)[a] was prospected. In May of this year the Miami, Duryea, Stonewall, and Isabella mills were working in all 27 stamps, and the Nugget, Baldwin, Golden Eagle, Irene, Silver Era, and Townsend mills, with a total of 65 stamps, were in process of construction. Lost Gulch was at this time coming into notice as a promising field for gold prospects. It is probably to this period that the former activity of the abandoned silver mines at Pioneer, 12 miles south-southwest of Globe, is to be referred, but no published record of their operations has been found.

In 1883 there were 12 mills reported in the vicinity of Globe working on silver and gold ores and having in all 86 stamps. The Silver King mine had reached a depth of 714 feet on a body of rich silver ore, which, however, gave out near this level. From this year on silver mining declined, and, although a little desultory prospecting and mining continued, and the Fame mine was exploited as late as 1889, the mines were one by one shut down, and the production of silver ores appears to have practically ceased by 1887.

The future prominence of copper as the principal product of the Globe district appears to have been at first unsuspected, in spite of the strong surface indications of the presence of copper ore, and those mines which subsequently became the largest copper producers were at one time worked for silver.

[a] The original Old Dominion mine is situated about 4 miles north of Globe, on a vein in quartzite. Its owners, the Old Dominion Company, afterwards purchased the old Globe mine, which is now the principal mine of the region and is popularly known as the Old Dominion mine. To avoid as much as possible the confusion which this duplication of names involves, the first mine, to which the name really belongs, will be referred to as the original Old Dominion. It at one time afforded handsome specimens of native silver and free gold from its upper levels, but is no longer worked by the company.

The first notices of copper prospecting are in the Arizona Silver Belt of July 11, 1878, where reference is made to the abundant copper ore revealed by the very superficial workings on the Globe and Globe Ledge claims. This ore seems, however, to have attracted little serious attention until 1881. About this time the Old Dominion Company erected a small copper furnace on the Western Pass road, about 6 miles nearly due west of Globe and about half a mile northeast of Bloody Tanks. The ore for this furnace was obtained from a vein in the schists near by, but appears to have been only a small pocket and the mine was soon abandoned. The smelter was moved to Globe and worked for a time on the siliceous copper ore from the original Old Dominion mine; but the company soon purchased the Globe mine, and in May, 1884, this was in full operation and produced 490 tons of copper from two 30-ton furnaces. From this time on the old Globe mine became generally known as the Old Dominion, while the original mine of that name was practically abandoned.

In 1886 the property of the Old Dominion Company was sold at auction to William Keyser, of Baltimore, the reported price being $130,000. The product at this time is said to have been about 10 tons per day from one furnace, and the total product from 1882 to September 1, 1886, is given as 22,800,000 pounds. There were in all 6 copper furnaces in the district, and mines other than the Old Dominion are credited with a total product of 1,000,000 pounds for the same period. At the end of this year the low price of copper, combined with the necessarily high operating expenses in a region where supplies were hauled by wagon from Wilcox, 120 miles away, compelled the copper mines to close.

Early in 1888 the Old Dominion Company was reorganized, work was resumed, and the sixth level opened from the new Interloper shaft. During this and the following year the mine produced 10,515,510 pounds of copper, and is said to have maintained an average annual production of about 8,000,000 pounds up to the close of 1893. The Buffalo mine was producing some copper ore in 1890, but the economic history of these years is largely that of the Old Dominion mine.

In 1892 the United Globe Company was organized and the Buffalo, Hoosier, and numerous other claims were consolidated into one group. Three years later the Old Dominion also changed hands.

The United Globe mines enlarged their plant in 1895, and began active operations in 1896, directed chiefly to the development of the Hoosier claim, which had produced considerable ore from bodies in limestone near the surface. There was a general revival of prospecting at this time in Lost Gulch and on Pinto Creek, and development work was in progress at the Continental mine, at the Black Warrior and Black Copper mines, then owned by one company. In Lost Gulch the Kasser mill of 10 stamps was operating for a time on gold ores.

In April, 1897, the Old Dominion mine, which had been producing steadily, with the exception of brief stoppages due to labor difficulties, shut down to await the arrival of the railroad, which was completed into Globe on December 1, 1898. The mine then resumed operations and has continued to produce copper up to the present time. It continues to be the only large and steadily productive mine of the region, although ores in considerable quantity have been shipped from time to time from the United Globe and smaller properties. The Continental mine, which had produced some rich copper ore, but not in shipping quantities, was bought by the Old Dominion Company in 1899, but has not yet been actively worked.

PRODUCTION.

In the Globe quadrangle the production of copper far exceeds in importance that of any other metal, and more than three-fourths of the whole output has come from a single mine, the Old Dominion (formerly known as the Globe). The total product of this property and the various mines of the United Globe group at the close of the year 1901 was a little over 118,000,000 pounds of copper. If an estimated 2,000,000 pounds additional be added to this to cover unrecorded and irregular shipments from smaller mines, there is obtained a total product for the quadrangle of, in round numbers, 120,000,000 pounds.

Statistics of the output of gold and silver are lacking. The McMorris mine, in Richmond Basin, which while not embraced by the Globe quadrangle comes within what is generally known as the Globe region, is credited with a production of nearly $150,000 in silver during 1880 and 1881.[a] The total product of this mine probably exceeded $300,000. Silver was also produced in the early eighties from the surface workings in Richmond Basin, in the form of nuggets, and from several small mines, such as the Fame, Centennial, Nugget, and others, lying north of Globe; but the total amount was probably not large.

Gold has been mined in small quantities in Lost and Gold gulches, the output from the former being given as $48,000 in 1896.[b] The production of this metal, however, has been intermittent, and the total is probably inconsiderable.

DISTRIBUTION OF THE ORES.

The ore bodies which have thus far proved of most importance in the Globe quadrangle occur in the Globe Hills, just north of Globe. The copper ores which have given the district its later prominence are found in the southern part of these hills, within a radius of 3 or 4 miles from Globe, principally in the properties owned by the Old Dominion and the United Globe companies, while the silver

[a] Files of the Arizona Silver Belt for 1881.
[b] G. W. P. Hunt, in the Report of the Governor of Arizona for 1896, p. 108.

ores, which first attracted attention to the region, were formerly mined in the northern portion of the hills and in the adjoining quadrangles to the north and east. Such old silver workings as lie within the Globe quadrangle have been idle for years. They are none of them extensive and are now of slight importance, and afford in their present condition little opportunity for scientific investigation.

Although the same rocks that make up the Globe Hills occur also in the northeastern quadrangle, where they have been fissured in a remarkable manner, no workable ore and very little mineralization has been found north of a line joining Sleeping Beauty Peak and Webster Mountain.

South of this line copper ores occur at the Black Warrior and Black Copper mines in Webster and Gold gulches and at the Geneva and Continental mines, while sufficient gold has been found in Lost and Gold gulches, both in small veins and in superficial gravels, to encourage prospecting and intermittent mining on a small scale since the discovery of the district.

In the vicinity of Liveoak Gulch the porphyritic facies of the Schultze granite has been much fissured and shattered, and is often conspicuously stained with carbonates and silicate of copper, while workable deposits of chrysocolla have been exploited on a small scale in the Liveoak and Keystone mines.

On Pinto Creek, near the mouth of Cottonwood Gulch, the schists are very much brecciated by numerous fissures, and show conspicuous green stains of copper, but no ore bodies have yet been found. In general it may be said that there is more or less mineralization at several points in the Pinal schists close to the contact with the Schultze granite, but ore in workable quantity has not been discovered.

In the diabase of Powers Gulch are a few small veins showing, in croppings and shallow prospects, some galena in rusty copper-stained quartz.

In the southern half of the quadrangle there is comparatively little mineralization, although bodies of ore have been found at the Summit, Cole & Goodwin, and Bobtail mines, in the large irregular area of schist covering much of the western slope of the Pinal Range. Some silver ore has been produced by the mines at Pioneer, but they lie just outside of the southern boundary of the quadrangle. On the northeastern slope of the range a little gold has been obtained from the gravels of Pinal Creek, but no workable gold-quartz veins have yet been found.

GENERAL CLASSIFICATION OF THE ORES.

The ores of the Globe district may be classed as (1) free gold ores, (2) native silver or silver-lead ores, and (3) cupriferous ores containing varying amounts of the precious metals. At the present time, however, ores of the first and second classes are mined on so small a scale and so intermittently that it is scarcely necessary to consider them. They play but an insignificant part in the mining industry of the quadrangle, and very little of scientific interest is to be gained from the present underground developments connected with their exploitation. It is to the cupriferous ores that the district owes its life, and with them that this report is most concerned.

The copper ores may be divided on genetic as well as practical grounds into (1) oxidized ores and (2) sulphide ores. To the former division belongs nearly all of the ore produced in the district up to the year 1901, when some small shipments of sulphide ore were made from the Summit mine. Sulphide ore, on the other hand, if there be excepted occasional bunches of chalcocite found with oxidized ore, as in the Buffalo mine, is of recent discovery, and a factor of increasing importance in determining the future of mining operations in this quadrangle.

As will be later shown, the sulphide ores are theoretically capable of further division into primary ores, or ores of original deposition, and secondary ores derived by subsequent chemical processes from the primary ores. The oxidized ores also may be conveniently distinguished as indigenous and exotic, the former being those produced by the oxidation of sulphides in situ and the latter those deposited after some migration from the place of sulphide oxidation. It is evident that this distinction can not always be made in practice, and the extent of the migration of the oxidized ores in solution is rarely determinable. Between the two kinds of ore no hard and fast line can be drawn, but the classification recognizes a factor in ore genesis which both observation and theory agree to be real, and which in the Globe district has a practical bearing.

MINERALOGY OF THE ORES.

The mineralogical character of the Globe ores is simple. The primary sulphide ores and those which in the absence of any evidence of secondary origin may be grouped with them are composed usually of rather crumbling, granular pyrite, with which is commonly associated some chalcopyrite. Of less frequent occurrence are galena and sphalerite, with occasionally the tungstate hübnerite, as in the Bobtail mine. The gangue is altered country rock, or quartz, the latter being rarely abundant, or sometimes calcite, as in the Cole and Goodwin mine.

Loosely coherent pyritic ore, often containing no visible chalcopyrite, is found on the eleventh and twelfth levels of the Old Dominion mine, between the fifth and sixth levels of the Grey mine, and in the Continental mine. It also occurs, with some chalcopyrite, finely disseminated through the granite-porphyry (Schultze granite) near the head of Gold Gulch.

Chalcopyrite is found abundantly in the Summit mine, where it forms the bulk of the ore, in the Cole & Goodwin mine with pyrite, in the Bobtail mine with sphalerite and galena, and in a quartz vein in Schultze granite at the Yo Tambien, a prospect on the west side of Pinto Creek, near the mouth of Cottonwood Gulch.

Galena occurs very sparingly in the quadrangle, and was seen only at the Bobtail mine, as occasional specks in the Cole & Goodwin ore, and in the partly oxidized ore of some prospects in Powers and Gold gulches. It probably occurs to some extent, however, in the argentiferous veins in the diabase of the northern Globe Hills, and was seen with sphalerite in the ores of Pioneer and Richmond Basin, which lie outside of the quadrangle.

Sphalerite is known only at the Bobtail mine and in minute quantities at the Cole & Goodwin mine.

Of the foregoing the pyritic ore of the deeper levels of the Old Dominion mine is regarded as most typically primary ore. It is less certain whether the galena and sphalerite are products of original ore concentration, but there is in this district no known evidence to the contrary.

The only secondary sulphide recognized in the quadrangle is chalcocite or copper glance. This occurs as a thin film coating fragments of chalcopyrite in the Summit vein, and is here indubitably of later origin than the chalcopyrite. The hematite associated with it probably represents part of the iron set free from the chalcopyrite in the change to chalcocite. In the Buffalo mine massive chalcocite occurs, altering to malachite. As it is found only in small residual masses and is the only sulphide present, no direct light is thrown on its presumable origin from primary sulphides. In the Old Dominion mine compact, massive chalcocite occurs within the zone of change from oxidized ores to pyritic ore, chiefly on the eleventh and twelfth levels. Some of the chalcocite is free from pyrite, but the latter mineral is often disseminated in small particles through the mass of the gray copper sulphide. When the chalcocite is examined closely, particularly with a lens, it shows an indistinct unevenness of texture suggestive of the obscurer forms of pisolitic structure observed in some bauxites. Critical scrutiny of the inclosed grains of pyrite discovers the fact that their outlines are rounded and that the chalcocite has a more or less distinct, concentric, shelly structure around each grain. These facts at least strongly suggest that the chalcocite has been formed at the expense of the pyrite, and that the minute structure observable in chalcocite now free from pyrite records the former presence of that mineral and its subsequent replacement by the sulphide of copper. This process will be discussed at greater length, however, in the pages devoted to ore genesis.

As might be expected, the oxidation of sulphides showing so little diversity as those in the Globe quadrangle, has resulted in mineralogically simple products. Arsenical and antimonial minerals, which in some copper districts accompany the sulphides and give rise, by oxidation, to various mineralogically interesting derivatives, are here unknown. Pyrite, chalcopyrite, and chalcocite have their sulphur replaced by oxygen, carbon dioxide, or silica, usually with accompanying hydration, and become hematite, limonite, cuprite, malachite, or chrysocolla. Azurite rarely occurs save as an occasional incrustation on malachite.

The hematite when not combined in an aphanitic earthy mixture with cuprite occurs as specularite, sometimes in a form of a loose powder of greasy feel, but more often in firm aggregates streaked with chrysocolla or malachite and containing little vugs lined with one of the latter minerals, which in turn is not infrequently covered with drusy quartz. The specularite is found usually in quartzite or limestone, often forming the gangue or matrix of bunches of oxidized ore.

The occurrence of limonite is similar to that of hematite, but it never has the unctuous, pulverulent form often taken by the latter. It is found principally in limestone, as a firm, aphanitic material, more or less cavernous in texture and passing occasionally into yellow, ocherous varieties. It is usually associated with the oxidized ores of copper, either as a "casing" between the ore and the limestone, or as a large mass within which the ore, if present, is found in bunches. It also occurs intimately mingled with the cupriferous minerals in the ore itself. Limonite is abundant in the Old Dominion mine, and appears to be in this district a characteristic accompaniment of oxidized copper ores in limestone.

Cuprite showing crystalline texture was noted only at the Continental and Buffalo mines. Mixed with hematite or limonite, however, it probably makes up a considerable part of the high-grade, aphanitic, brown copper ore found in the Old Dominion and other mines in the Globe Hills.

Malachite, or the green carbonate of copper, is very abundant, particularly throughout the Globe Hills, but never, so far as seen, forms large masses. It occurs characteristically as small stringers or veinlets, cutting the other oxidized ore minerals or lining small vugs. It is particularly conspicuous in connection with ore bodies in quartzite, as the innumerable minute fissures formed in this brittle rock, many of them of microscopical size, are usually filled with malachite, giving a bright-green tint to the whole. In many cases the malachite has apparently directly replaced the quartzite, as the microscope shows crystals of the carbonate projecting from the microscopical veinlets into the substance of the rock. Associated with chrysocolla it forms a considerable proportion of the ore of the Buffalo, Big Johnnie, Buckeye, and other mines in quartzite. It occurs as veinlets in the chrysocolla of the Keystone mine, and as a conspicuous green stain over much of the granitic porphyry in the vicinity of Liveoak Gulch.

Azurite, or the blue carbonate of copper, is rarely seen, druses or incrustations on malachite.

Chrysocolla is an abundant and important ore mineral in the (although its high contents of silica and water make it relative compared with ores containing cuprite or malachite. It varies from delicate apple-green or turquoise-blue tints to dark green, br the darker tints being apparently due in most cases to the presen manganese.

The green and blue varieties are common in all the oxidized ore Dominion, Buffalo, and other mines and prospects in the Globe occurring as little bunches and veinlets in the cryptocrystalline, imp of the high-grade brown ore. A pure, greenish-blue chrysocolla with like banding forms the ore of the Keystone mine, where it occurs as granitic porphyry, and is common in neighboring prospects north o Tanks.

The same mineral constitutes the ores of the Black Warrior, Gene Black Copper mines, occurring chiefly as a replacement and mineraliza dacite tuff. Much of this ore is dark colored, owing to the presence of ganese oxide, and that of the Geneva especially is of very striking appea It consists of kernels of black or dark olive-green chrysocolla of very irre shape embedded in lighter-colored varieties of the mineral, ranging in tint a delicate turquoise blue to a deep bottle green, the whole ore having a resi luster. These paler-tinted varieties are often arranged in fine concentric ba about the dark kernels, and as they do not always completely fill the interstic between the latter, the resulting cavities form little vugs, usually lined wi pale-blue, botryoidal chrysocolla. Field relations show that this ore occurs as replacement of dacite tuff, and a study of specimens indicates that the dark kernels, which owe their depth of color to the presence of oxide of manganese, probably represent original glassy particles of dacite and possibly small schist fragments in the tuff. Traces of flow structure and of original partly crystal-line texture can occasionally be detected, and residual flakes of biotite, such as occurs in the dacite, are not uncommon within the dark chrysocolla. The present boundaries of the kernels are not, however, identical with those of the supposed original clastic particles. The latter have been rounded and embayed in the process of ore deposition, and in part replaced by the banded chrysocolla, which apparently occupies in the main the place of the former fine interstitial material of the tuff.

Native gold, silver, and copper were seen in place only within the zone of oxidation, although the first-named mineral probably occurs to some extent in the district as a primary ore constituent. Gold occurs as thin, hackly plates and short wires in the massive, impure cuprite of the original Old Dominion mine. More or less native silver has probably been found in many of the oxidized ore deposits in the district, but was seen at the time of visit only in the Continental mine as minute flakes in calcite accompanying cuprite. Native copper in small hackly particles is abundant in certain parts of the Old Dominion mine, particularly in mineralized shattered quartzite within the zone of oxidation.

PARAGENESIS.

By paragenesis is meant the association of the various ore and gangue minerals, with special reference to the order and mode of their formation.

As far as known the minerals of the primary sulphide ores were contemporaneously formed and exhibit no regular sequence. Thus, in the Bobtail mine chalcopyrite, sphalerite, galena, pyrite, and hübnerite occur together in a quartz gangue, none of the minerals named showing evidence of earlier or later origin than the others.

The secondary sulphide chalcocite was the latest of the sulphides to form, as shown by its coating fracture surfaces of chalcopyrite in the Summit mine and its occurrence near the bottom of the zone of oxidation in the Old Dominion and Grey mines.

The oxidized ores are, of course, of generally later date than the sulphides, although it must be borne in mind that the formation of chalcocite is probably still in progress below the zone of complete oxidation.

Cuprite, native copper, and hematite appear to be characteristic of the lower portion of the oxidized zone and probably tend in such a position to form first from the sulphides. Occasionally, however, as in the Buffalo mine, chalcocite changes directly into malachite. The character of the transformation depends upon the nature of the solutions effecting it, and that in turn upon the depth at which the process takes place and the materials through which the solutions have previously percolated. As a rule chrysocolla is older than malachite when the two minerals occur together. The silicate, other things being equal, seems to form at a greater depth in the zone of oxidation than does the malachite. Azurite, when it occurs, is of later origin than the malachite.

The formation of quartz and calcite is not limited to any single phase or period of ore deposition, but traverses the entire range of mineralization from the primary sulphides to the latest oxidized ores. These gangue minerals are rarely abundant, however.

Exceptions to the usual sequence of the ore minerals as just outlined are by no means difficult to find, and illustrate the variable and complex factors concerned in ore genesis. Thus, a specimen from the Old Dominion mine, seen in into the diabase by the process of metasomatic replacement. Such ore possesses no regular vein walls, but grades gradually into altered diabase containing disseminated pyrite. Such a process, while it does not extend to a sufficient lateral distance to destroy the general lode-like form of the deposit, nevertheless tends to connect fissure veins through intermediate forms with the deposits belonging to the other classes. The pyritic lode of the Continental mine, which is in a granite-porphyry facies of the Schultze granite, is also a stringer lode and is accompanied by considerable metasomatic mineralization of the neighboring country rock.

When, as is the case in the I X L, Big Johnnie, Buffalo, and Copper Hill mines, lodes pass upward from diabase into overlying quartzite, the latter rock usually shows the greater mineralization. The only known exception to this is the Josh Billings vein, in which the ore occurs principally in the diabase.

Although the lodes often contain excellent ore, it has not yet been found in such abundance as in the large masses in limestone, which have supplied most of the copper from the district for the last twenty years.

All of the important ore bodies thus far discovered in limestone, with the exception of one formerly worked in the Buffalo mine, lie on the southeast side of the Old Dominion fault, and have been worked through the Old Dominion and Hoosier mines. In the former property there is exposed in the hanging wall of the master fissure—the Old Dominion fault—a thickness of from 350 to 550 feet of the Globe limestone resting upon the quartzites of the Apache group. The ore bodies occur rather irregularly throughout this limestone section from the top to the bottom. In general they are rudely lenticular in shape and lie roughly parallel with the nearly horizontal bedding of the limestone. Some of them are directly connected with the Old Dominion fault, the ore forming the hanging wall and extending irregularly for 20 or 30 feet out into the limestone. Others, although never far from the Old Dominion fault, are completely inclosed within this rock, which, however, always shows more or less fissuring, such as may have given access to the ore-bearing solutions. Some of these ore masses have been of large size, one in the Old Dominion mine having been about 200 feet long, 100 feet wide, and 60 feet thick. This, however, was not wholly within the limestone, but was partly in quartzite, and really falls also into the third general class of the ore deposits of the district. Other masses of ore not coming strictly within the definition occur in the Old Dominion mine at the contact of limestone with overlying dacite. The ore, however, occupies space formerly filled with limestone and not with dacite, and the form of such deposits is similar to that occurring wholly in limestone.

The ore of these masses in the Globe limestone is always oxidized and often accompanied by large quantities of hematite or limestone. It sometimes rests it occupies a fault fissure opened prior to ore deposition, and might perhaps be classed with the lodes.

ALTERATION OF THE COUNTRY ROCK.

Owing to the prevalent oxidation and the absence of extensive mine workings in connection with sulphide ores, the Globe region does not at present offer favorable opportunities for the study of metasomatic alteration of the country rock as an accompaniment of original ore deposition. Such alteration as was observed was not conspicuous, and was not particularly studied. In very few cases have the developments on sulphide ores gone to such a depth as to entirely eliminate the action of descending surface waters.

GENESIS OF THE ORES.

The little mining development so far accomplished upon the primary sulphide ores has brought to light no evidence against the commonly accepted view that such ores were deposited by ascending solutions of originally meteoric water which had become charged with ore-forming constituents in the course of a slow and devious underground circulation. Their metalliferous contents were probably derived from the deep-seated rocks of the region. The diabase, which was so extensively intruded into the Carboniferous and older rocks, contains abundant augite, olivine, and magnetite, and is obviously a likely source of supply for at least some of the ore constituents. In order to test this hypothesis, 10 grams of the fresh diabase, of which a chemical analysis and petrographical description are given on pages 83 to 85, was examined in the Survey laboratory by Dr. E. T. Allen and the presence of a trace of copper determined. As the specimen came from an unfissured mass exhibiting no signs of mineralization, and is shown by the microscope to be almost ideally fresh, it is probable that the copper is an original constituent of the rock and a source of at least a part of the copper concentrated by natural processes in the ore bodies.

As fissuring, accompanied or followed by the original mineralization of the district, is the important event recorded in the geological history of the region succeeding the intrusion of diabase, it is probable that here, as in other mining districts, there is a close genetic relationship between the manifestations of volcanism and the subsequent ore deposition. The intrusive masses not only supplied ore constituents, but were probably partly responsible for the fissuring, and supplied heat and chemical activity to the underground waters.

In spite of the limited amount of mining work done upon the sulphide ore bodies of the quadrangle, the evidence for the secondary origin of the chalcocite is satisfactory. In the Summit mine this mineral occurs probably at less than 200 and reflected light, but nothing accounting for this chemical peculiarity could be detected.

The process of sulphide enrichment appears to have worked downward, keeping 200 feet or more in advance of distinct oxidation. Chalcocite thus occurs as residual masses in the oxidized ore, and as bunches in pyrite below the limit of oxidation. Below the twelfth level chalcocite will probably be less abundant, and it is rather doubtful whether it will be found in any quantity on the thirteenth level when that depth is reached.

The bulk of the oxidized ores are indigenous, i. e., occupy substantially the places of formerly existent sulphides, the latter having been altered in the usual manner by descending solutions, which, starting at the surface with oxygen and carbon dioxide, constantly gathered new materials and effected manifold chemical changes in the ores in their downward progress. Such apparently are the oxidized ores of the Old Dominion, Hoosier, Buffalo, and other mines in the Globe Hills. But even in these cases there has evidently been some migration of the ores during the general progress of oxidation, although it is difficult to determine how extensive this movement has been. In the Buffalo mine, for example, the occurrence of kernels of chalcocite surrounded by malachite shows that the change has been on the whole in situ. But microscopical study of the oxidized ore indicates, on the other hand, that some of the malachite has directly replaced the quartzite and occupies a position not previously filled by a sulphide.

As far as known, no sulphides have been found in the large ore bodies occurring in limestone in the Old Dominion mine, and there is no direct evidence that they were ever present. But reasoning from analogy, with deposits of like form and similar geological surroundings, known in other districts, it is fair to suppose that these masses were originally deposited as sulphides, although it is not safe to assume that these sulphides were identical in character with the pyritic ores now known in the diabase of the lower levels. It is very probable that they were more cupriferous.

With the oxidation of these ore bodies much of the iron and copper passed into solution as sulphates, carbonates, or silicates, and this change was unavoidably accompanied by migrations of the different ore constituents within the oxidizing mass. That such, indeed, took place is seen by the structure of the oxidized ore, in which stringers or bunches of one ore mineral occur inclosed within another. Moreover, these ore solutions can scarcely have been confined within the space originally occupied by sulphide ore. They undoubtedly took advantage of such mechanically formed spaces as may have opened since the sulphides were originally deposited to transport ore into new crevices, and very probably replaced to some extent the inclosing limestone and such of the shattered quartzite as lay within reach of their attack.

In the case of the chrysocolla deposits of the Black Warrior, Geneva, and Black Copper mines, the ores occur as replacements of dacitic tuff, or possibly dacite in the last-named property, and their structure is such as to indicate strongly that they have been deposited directly in the tuff as the hydrous silicate of copper, and do not represent the alteration in place of former sulphides. Proof of this hypothesis is, perhaps, not to be had. But the total absence of sulphides, combined with the lack of iron oxide and the fact that the ore is practically a single mineral rather than a mixture such as results from the oxidation of more or less pyritic ores, are points in its favor. Furthermore, the structure of the chrysocolla is closely and minutely related to that of the tuff it has replaced, which would probably not be the case did the ore result from the alteration of former bodies of sulphides. For, even if the sulphides preserved some vestiges of the original texture of the tuff, the further change into chrysocolla could scarcely fail to obliterate them entirely. It is therefore concluded that the chrysocolla ores of these mines are probably exotic, although it is admitted that actual proof of this is, from the nature of the case, not at hand.

The sources of the solutions that deposited the hydrous silicate of copper are unknown. Although they are always associated with much fissuring, a large part of this is later than the ore, and none of the fissures that have been cut in the underlying schist show such mineralization as would be expected had they served as channels for ore-bearing solutions capable of depositing the overlying ore bodies. The hypothesis that the ores have reached their present position by direct ascent through these fissures in the schists, while attractive at first glance, has insufficient support as far as present developments go.

A second hypothesis is that they may have come in laterally along the pervious beds of tuff, carrying the copper first as carbonate, afterwards to be transformed to silicate by the abundant silica present in the glassy tuff, the ready solubility of which is shown by the frequent occurrence of opal and chalcedony in the tuffaceous and massive dacite. Probably there were scattered over the old surface of shattered schist upon which the tuff was laid down surficial deposits containing carbonate of copper, much as, at the present day, slightly waterworn gravelly detritus cemented by impure malachite may be seen in Webster, Lost, and Gold gulches, usually just above the level of the existing stream channels. Such deposits show that solution and transportation of ore may be effected by the mere passage of meteoric waters over the surface of a generally mineralized region. The covering of such a surface with a permeable mantle of tuff offers exceptional opportunity for the solution and transport of the scattered, low-grade surficial ore, and its concentration in favorable places at the base of the tuff through the agency of what are practically surface waters. The deposition of this exotic ore would be particularly favored by a fault, such as that at the Montgomery claim, which should drop the tuff against older, less permeable, and less chemically active rock, thus forming a depositional trough.

It is believed that such an hypothesis best accounts for the chrysocolla ore of the Black Warrior, Geneva, and probably, also, that of the Black Copper, mines. The ore is exotic, and has been derived, not from sulphides in place, but probably from the lateral transport and concentration of scattered surficial deposits of predacitic origin, which were themselves formed by the oxidation and weathering of sulphides.

The genesis of the chrysocolla of the Keystone and neighboring veins in granite-porphyry is not clearly understood. The purity of the chrysocolla, its vein structure, and the absence of evidence of sulphide oxidation from the vein and wall rock are suggestive of an exotic origin of the ore, and its deposit in the fissure as hydrous copper silicate. The present depth of the Keystone mine, however, is not sufficient to determine the real genesis of the ore body. The occurrence of some unoxidized pyrite in a stringer near the mouth of the lower tunnel indicates that if the chrysocolla is to give place to sulphides in depth, the point of change should not be far off. It is hoped that the mine will be successfully exploited to a sufficient depth to thoroughly expose this interesting deposit.

AGE OF THE ORES.

As, in this district, primary sulphide ores are found in fissures cutting diabase, they were evidently deposited after the eruption of that rock. Similar original ores also occur in Pinal schist, in which case there is nothing in their surroundings to show that they are not much older than the ores in diabase. But as they are even less deeply oxidized than the latter, it seems reasonable, in the lack of distinct evidence to the contrary, to refer all of the primary sulphide mineralization to one period, subsequent to the great disturbing and mineralizing event in the geological development of the region—the diabase intrusions.

Although the fact that the primary ores are later than the diabase is readily established, their relation to the dacite is less easily determined. It has been shown that the region was probably faulted after the diabase intrusion and long before the eruption of the dacite. The results of this faulting were, however, greatly obscured by the postdacite faulting, probably in late Tertiary time. There is some question whether or no this earlier faulting was important, and whether the original mineralization is related to it or to the postdacite faulting. Owing largely to the usual oxidation of the ore, no thoroughly conclusive evidence for the decision of this question could be obtained at any point. That the former of these alternative hypotheses, namely, that the sulphide ores are older

DESCRIPTIONS OF MINES.

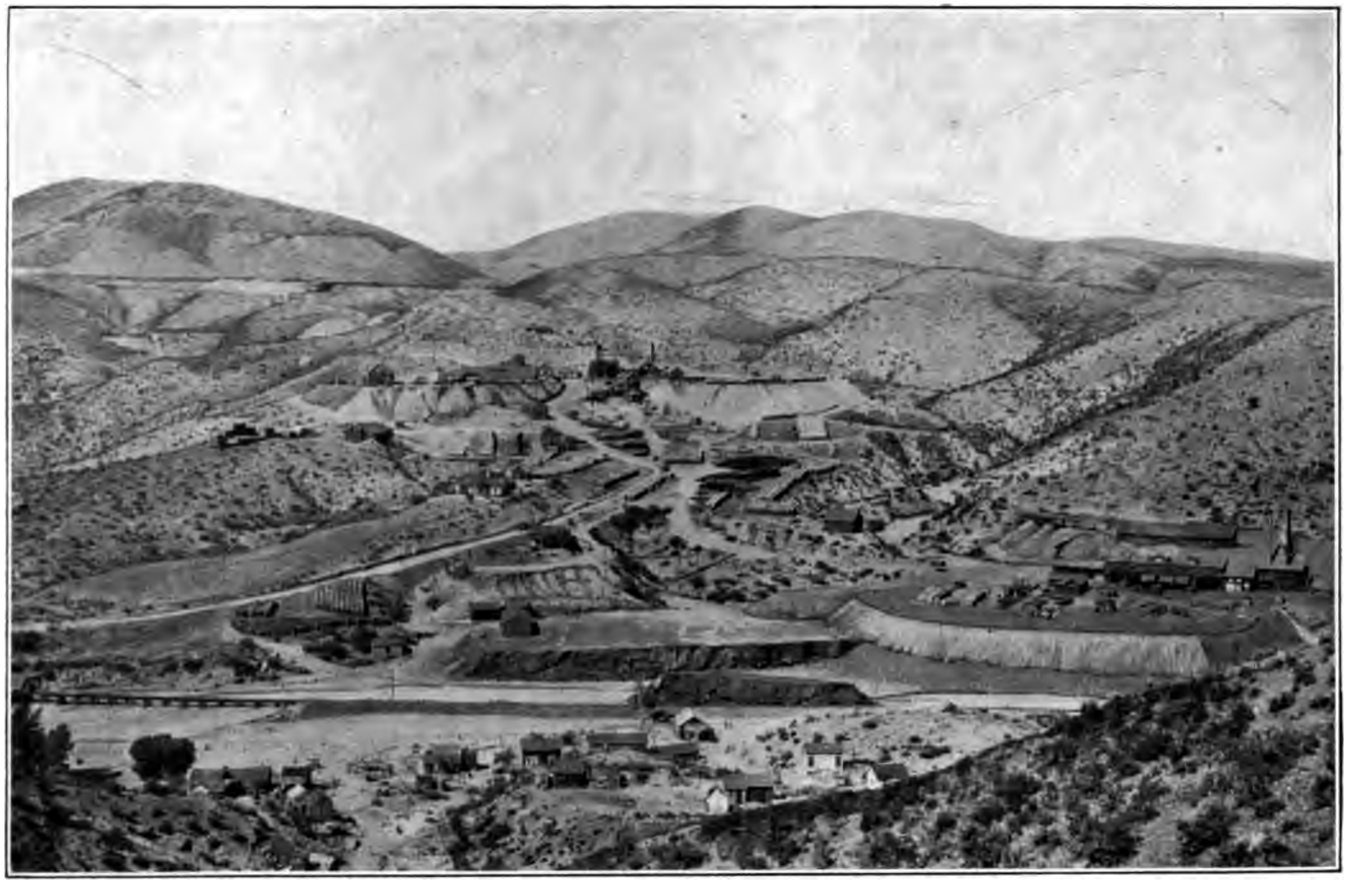
OLD DOMINION MINE.

Situation.—This property, formerly known as the Globe mine, comprising a compact group of nine claims, lies on the east side of Pinal Creek, just north of the town of Globe. Of these claims, the Globe and Globe Ledge, located upon a strong fault, are the most important, and have produced the bulk of the ore. Some ore has also been mined from the Alice claim, which is on a fissure southeast of the main Old Dominion fault.

History and production.—The Globe claim was staked in 1875, and was the first mining location in the district. It apparently attracted but little notice for several years, although some superficial work was done in search of silver ore. In 1881 the extraction of copper ore began, and the mine, shortly after purchased by the original Old Dominion Company, soon became the largest and steadiest producer of such ore in the region. In 1886, after yielding between 18,000,000 and 19,000,000 pounds of copper, the mine was sold at auction to William Keyser, of Baltimore. Early in 1888 a new company was organized and the mine was operated almost continuously up to 1895, when it was sold to Lewisohn Brothers, of New York, and subsequently transferred to the present owners, the Old Dominion Copper Mining and Smelting Company, of Boston. The mine produced nothing in 1895, but resumed production in 1896 and reached its maximum output in 1901, the latest year for which figures were obtainable for this report. During much of the time from April, 1897, to the completion of the railroad, at the close of 1898, the mine was idle.

The total production of copper from the Old Dominion mine up to the end of 1901 is a little less than 106,500,000 pounds. Up to the year 1900 no returns of the silver and gold in the copper bullion are obtainable, while the figures for 1900 and 1901 are, by the desire of the company, withheld from publication.

Development.—The underground workings of the Old Dominion mine comprise 12 levels of generally linear plan (Pl. XXII), extending northeast and southwest along a zone of faulting. The main adit is a 3-compartment vertical shaft 827 feet deep, sunk through the hanging wall on the Interloper claim. With this shaft all the levels are directly connected except the first level or "mule tunnel," which has its own adits at the level of the shaft collar. There are also several unused shafts and some short tunnels connecting with old workings above the mule tunnel, as well as some open cuts from which ore is still being mined. From the second and fourth levels drain tunnels have been run out to the surface southwest of the Interloper shaft. The levels from the first to the eighth are from 58 to 72 feet apart, while from the eighth to the twelfth



THE OLD DOMINION MINE AND SMELTER, FROM THE WEST.

they are separated by intervals of 100 feet. The total length of ground which is more or less explored by these workings is about 3,600 feet and the total depth about 1,000 feet. The largest ore bodies have been found to the northeast of the shaft, and the greatest development has consequently been in that portion of the mine. The principal work on the Alice claim consists of two tunnels, run in from the northeast side of Alice Gulch and connected by raises with each other and with the first level of the main Old Dominion workings. A general plan of the underground workings of the Old Dominion mine is shown in Pl. XXII and an elevation in Pl. XXIII.

The ore is carried on an aerial tramway about 1,200 feet in length down to the company's smelter on Pinal Creek. (Pl. XXI.) The smelter is equipped with four stacks, of which but one is usually in steady operation, with an average output of about 13 tons of copper per day. As all of the ore thus far mined has been oxidized, it is smelted directly without previous roasting.

The country rock.—The rocks met with in the Old Dominion workings are the quartzite of Apache group, the Globe limestone, diabase, and dacite. The quartzite is similar in character to that occurring on top of Buffalo Ridge, but in the Old Dominion mine it is not exposed on the surface except at the northeast end of the Globe claim. It occurs in beds of varying thickness up to 6 feet, or possibly more, and ranges in texture from pebbly grits to fine-grained vitreous varieties such as form the crest of Buffalo Ridge. The maximum thickness of the quartzite as exposed in the mine workings is about 500 feet, but as part of the quartzite in this section is much crushed and disturbed by faulting, the actual thickness of the beds may be considerably less than this. The quartzite beds have a general southerly dip of from 10° to 20°, but, as will be shown, they are locally much disturbed.

The Globe limestone overlies the quartzites of Apache group with apparent conformity. The latter relation, however, is difficult of proof owing to slipping and mineralization along the contact between the two rocks. At the surface the limestones are gray in color and thick bedded, as may be well seen in the limestone quarry east of the Interloper shaft. These beds are probably Upper Carboniferous, although no fossils were found at the mine. The beds at the surface are nearly horizontal, but in general throughout the workings they show a southerly dip of about 20°. The thickness of the limestone exposed in the Old Dominion mine has not been accurately determined. It is between 350 and 550 feet, and is probably not far from 500 feet. It is highly probable that the lowest beds are of Devonian age, but in the absence of fossils in the mine workings or of any well-marked stratigraphical plane of division, the beds belonging to these periods were not discriminated.

The lithological character of the diabase of the Old Dominion and neighboring mines has been fully described on pages 80 to 85 of this report. Here, as elsewhere in the Globe region, it is intrusive into the Apache group and Globe formation, chiefly as a sill of unknown thickness which is apparently intruded at the same stratigraphical horizon as that on the northern side of Buffalo Ridge. In the Old Dominion mine, as in that ridge, the Apache group immediately above the diabase is characterized by a few feet of rather thin-bedded reddish pebbly grits, but the intrusion of the diabase has not been confined to the injection of a single great sill. It has also cut irregularly across the beds as will later be shown. As a rule, the diabase seen in the Old Dominion workings is not so coarsely crystalline as that found in the middle of the large diabase areas of the quadrangle or as the typical and fresh facies forming the top of Black Peak. On the contrary, it is frequently almost aphanitic near its contact with the limestones and quartzites.

The dacite forms part of an irregular sheet whose geological relationships and petrographical characters have been described on pages 88 to 94. This rock is found only at the southwest end of the mine, where its relation to the older quartzite, limestone, and diabase is that of a flow resting upon an old surface of erosion which slopes down toward Pinal Creek. This simple structure has been modified, however, by a series of faults which will presently be described. Overlying the dacite flow are the conglomeratic beds of the Gila formation. The Gila formation and the dacite are not ore bearing, and the under surface of the latter rock limits the ore-bearing ground of the Old Dominion mine to the southwest (see Pl. XXIII).

The fissures.—The most important fissure in the mine, which will be referred to for convenience as the Old Dominion fault, finds prominent expression on the surface. Its general strike is about north 55° east, and it dips southeast at an average inclination of 55°, becoming steeper, however, below the ninth level. Passing just north of the little dacite knob above the mine buildings, the outcrop of the fissure crosses diagonally the ridge between Buffalo and Alice gulches, its course being marked by a line of shafts and open cuts, and descends into Alice Gulch, where for a few hundred feet it is not directly exposed. It is clearly traceable, however, over the southern slope of Buffalo Ridge just north of the Globe shaft, crosses Alice Gulch north of the Hoosier shaft, and continues northeastward toward the Grey shaft. The fissure is plainly a normal fault, as shown by the dropping of the Globe limestone against quartzite of the Apache group, and of dacite against diabase. The throw of the fault as measured by its displacement of the dacite is about 100 feet. But the present relative positions of the Paleozoic beds on each side of the fissure demand the existence of a much

greater displacement, probably as much as 1,000 feet. It is thus evident that the Old Dominion fault represents more than a single movement, about 900 feet of the throw being predacitic and about 100 feet postdacitic.

Throughout the greater part of the mine the foot wall of the Old Dominion fault is diabase, usually soft and decomposed for some distance from the fissure. The hanging wall varies, being mainly limestone in the upper levels (see Pl. XXIV), although quartzite, and finally diabase, predominates in the lower levels. Although the mine plats show many undulations in the foot wall, its appearance is often strikingly regular, as may be seen in Pl. XXV, *A*. It is usually easily recognized, and is rarely penetrated for any distance by the workings. The texture of the diabase is somewhat variable, and is frequently fine grained or even aphanitic, resembling facies elsewhere found near intrusive contacts, such as in the north crosscut in block vii,[a] on the tenth level, where the quartzites rest upon what appears to be a sill-like intrusion of diabase. The latter rock is aphanitic at the contact, but shows fine acicular feldspar crystals a few inches away. In block xxix, second level, where quartzite is exposed for a distance of about 40 feet in the bottom of the main drift, and near the line between blocks xxx and xxxi, on the same level (Pl. XXIV), where the drift passes from diabase into quartzite, the two rocks are separated by eruptive contacts near to which the diabase is unusually fine in texture. This quartzite near the northeast end of the second level is apparently in the foot wall of the Old Dominion fissure and inclosed in diabase, much as is the limestone between the fifth and seventh levels.

There are certain exceptions to the statement that diabase forms the foot wall of the mine, and probably the most remarkable of these is found on the sixth level, where for a distance of over 300 feet along the drift the foot wall is composed of limestone in nearly horizontal beds, which in block xi are irregularly intruded by aphanitic diabase. On the southwest the limestone is separated from the usual diabase of the foot wall by a vein of earthy hematite striking northwesterly and dipping southwest at 45°. On the northeast the contact between the limestone and diabase is marked by a fault fissure carrying a little crushed rock and traces of ore. A northwest crosscut has been run into this limestone for 300 feet without passing through it. Part of this same mass of limestone appears on the fifth level, in blocks xii, xiii, and xiv, but it is not known on the seventh level, where crosscuts show that it is underlain by diabase. There is thus inclosed within the diabase of the foot wall a block of limestone strata at least 300 feet square and probably something over 100 feet in thickness. On three sides the beds are cut off sharply by fissures, showing at least some

[a] The convenient notation employed in the mine is retained in Pls. XXII, XXIII, and XXIV, and is self-explanatory.

movement. The fourth side is as yet unexplored. The character of the upper and lower surfaces of this block are unknown, but they are probably intrusive contacts. The general position of the block of limestone is shown in fig. 7, which is a section across the mine on the line between blocks xi and xii.

Faulting alone, subsequent to the intrusion of the diabase, can not account for the occurrence of the limestone in the foot wall at this place. It is neces-

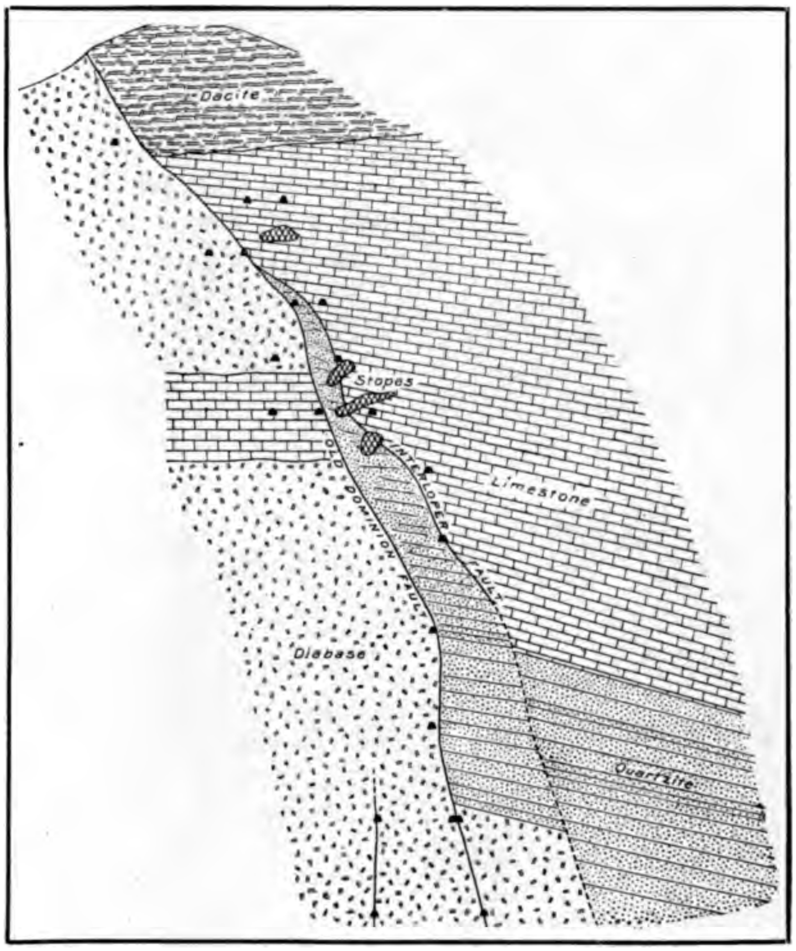
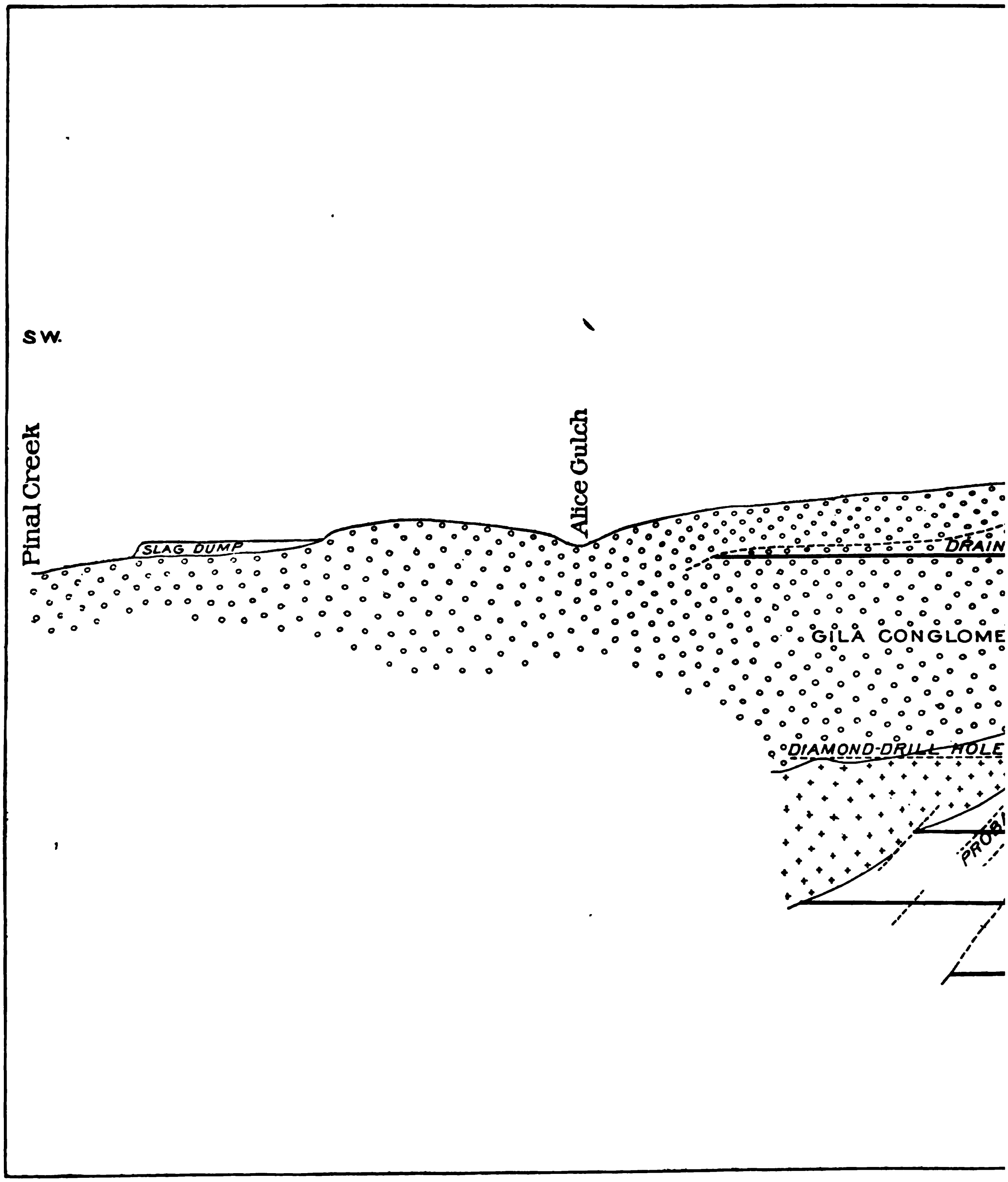


FIG. 7.—Diagrammatic cross section through the Old Dominion mine, showing the occurrence of a mass of limestone in the diabase of the foot wall.
Scale: 1 inch = 200 feet, approximately.

sary to conclude that it is a mass enveloped by the diabase at the time of intrusion, although some movement has subsequently transformed eruptive contacts in part into fault fissures.

The occurrence of this block in the foot wall, taken in connection with the known stratigraphical sequence in the hanging wall, shows that the initial Old


SW.
Pinal Creek
Alice Gulch
SLAG DUMP
DRAIN
GILA CONGLOME
DIAMOND-DRILL HOLE

Dominion fault antedated the intrusion of the diabase, and probably became in greater part a surface of eruptive contact. This conclusion is in harmony with the frequently fine-grained texture of the diabase near the fissure, a feature known to be characteristic of it in proximity to igneous contacts.

As will be shown when the ore bodies are described, there is evidence that the original mineralization is older than the dacite. It will also be shown that in the lower levels ore occurs in the Old Dominion fault in diabase. Consequently a part of the faulting along the Old Dominion fissure, and that part which was followed by mineralization, took place after the diabase had solidified but before the dacite was erupted. The truth of this is borne out by the following description of the Interloper fault, a branch of the main fissure, showing a displacement that demands in the latter a greater postdiabase throw than the 100 feet of postdacite movement alone would allow.

The preceding discussion has related to the main fissure, here called the Old Dominion fault, which has been shown to have been originally an intrusion fault, then in part a plane of eruptive contact, which was afterwards revived as a postdiabase fault of unknown throw and again reopened as a postdacite normal fault to the extent of a throw of 100 feet. There are, however, several other important fissures encountered in the mine, which are certainly in part and probably wholly later than the diabase intrusion.

The most notable of these faults, and one that has had much influence upon the genesis of the ore bodies, lies in the hanging wall of the Old Dominion fault, and like the latter has a southwesterly dip varying from 50° to 60°. This fissure, which may conveniently be designated as the Interloper fault, is distinctly recognizable on the second level, where with the Old Dominion fault it incloses a mass of crushed quartzite of lenticular plan (Pl. XXIV) extending southwestward for a distance of 500 feet from the Mooney shaft in block xvii. The hanging wall of the Interloper fault on this level is limestone.

On the third level the horizontal section of the lenticular wedge of quartzite lying between the two faults becomes both longer and broader. It here has a length of over 1,100 feet, and the maximum distance separating the two faults, which coalesce at the points of the lens, is about 175 feet.

On the fourth, fifth, and sixth levels the Interloper fault has been less continuously exposed than in the upper workings, but is recognizable at several points as a well-marked fault, usually having quartzite of the Apache group on its foot and Globe limestone on its hanging walls. Its maximum distance from the Old Dominion fault varies from 100 to 150 feet on these levels.

Below the sixth level the Interloper fault can not be identified with certainty among the fault slips of similar trend cut at various points in the workings.

The throw of the Interloper fault has not been determined. The cross section shown in fig. 7 indicates a displacement of about 400 feet. But the quartzite forming the upper portion of the wedge between the Interloper and Old Dominion faults is so crushed and disturbed that it can not be safely taken as a measure of the throw, which may be considerably less than 400 feet. This fault was probably formed after the intrusion of diabase and before the eruption of dacite.

The Alice vein, as exposed at the surface, is approximately parallel with the Old Dominion fissure, and lies from 300 to 500 feet southeast of the latter. The vein is wholly in limestone as far as explored, and has a southeasterly dip ranging from 45° to 60°. Between the Alice vein, which as seen on the surface is a mineralized limestone breccia, and the Old Dominion and Interloper faults the Globe limestone is cut by numerous faults, usually showing abundant soft gouge, indicating recent movement. These fissures have not been systematically explored, although they are often associated with bunches of ore in the limestone. They have various trends, and although the greater number of them are approximately parallel with the Old Dominion fault, others depart as much as 90° from this strike. They sometimes intersect in a perplexing fashion, as may be seen in the Alice workings. The Alice tunnel (see Pl. XXII) in its curved course from its mouth to its connection with the Alice crosscut makes a turn of about 90°, and apparently follows more than one of these fissures, which intersect at oblique angles and have various dips. In the first 200 feet the tunnel appears to follow the Alice vein, which, however, shows much recent movement. Near the Alice crosscut the drift follows a strong nearly north-south fissure, exhibiting evidence of considerable recent slipping. This is known in the mine as the Alice fault, and will be again referred to in considering those recent faults that have modified the ore bodies.

The dislocations occurring between the Old Dominion fault and the Alice vein appear to be for the most part minor faults, which do not cross into the foot wall diabase.

Although the diabase of the foot wall is practically unexplored, except on the first level north of the Globe shaft and on the eleventh and twelfth levels, yet enough has been done to indicate that it is traversed by fissures which, while roughly parallel with the Old Dominion fault, dip steeply in the opposite direction, i. e., to the northwest. Thus the north vein, which has been drifted upon north of the old Globe shaft, dips northwesterly at angles varying from 50° to 70°. It approaches the Old Dominion fault as it is followed upward, and must meet the latter just above the old workings from the Globe shaft.

On the eleventh and twelfth levels two distinct veins, diverging northeastward

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On the eleventh and twelfth levels two distinct veins, diverging northeastward

from the Interloper shaft, have been drifted on, as shown in Pl. XXII and fig. 7. It seems likely that the more northerly one, which is nearly vertical, is a fissure in the foot wall similar to the north vein near the Globe shaft, while the southerly one seems to be the main Old Dominion fault, although hardly enough work had been done in 1901 to put this beyond question.

All the fault fissures encountered in the Old Dominion mine show more or less recent movement, and are usually accompanied by soft gouge.

Character and occurrence of the ore.—All of the ore commercially extracted from the Old Dominion mine up to the present time has been oxidized ore, and contained no sulphides. Sulphide ores occur in the lower levels, but no attempt has yet been made to work them on a commercial scale, and they hold a different relation to the country rock from that of the great bulk of the ore which has given the mine its prosperity.

In its commonest form the ore is a dark reddish-brown, compact mixture, showing no crystalline structure, and composed chiefly of the red oxide of copper with more or less limonite or hematite. The color of this material varies with the proportions of cuprite, limonite, and hematite, being sometimes yellowish, dark brown, or nearly black. The dull tint of the compact earthy oxides is nearly always enlivened by bunches and veinlets of malachite and of blue or green chrysocolla. Ore of this character is often accompanied by large masses of the specular variety of hematite, usually carrying too little copper to pay for working, or by bodies of equally low-grade, cellular limonite. Native copper is sometimes an important ore constituent, and is particularly common in ore occurring in quartzite.

Quartz occasionally occurs in beautiful translucent druses coating chrysocolla or malachite, and crystals of calcite are sometimes found in vugs. But aside from such secondary occurrences, the deposit is free from these common gangue minerals. Azurite is sparingly present in ore bodies near the surface, and native silver has been reported from the old superficial workings.

There are frequently associated with the oxidized ores, and sometimes filling seams in the neighboring limestone, masses of waxy, clay-like material of various degrees of firmness and ranging in color from yellow to pale apple-green. Rough chemical analyses show that this substance is essentially a hydrous silicate of alumina, or a clay, containing in some cases as much as 7 per cent of magnesia, and in the green varieties a little copper, which is said to occasionally exceed 6 per cent, thus becoming a low-grade ore.

The important ore bodies so far exploited in the Old Dominion mine lie within the limestones and quartzites forming the hanging wall of the Old Dominion fault. In general these bodies are rudely lenticular and lie roughly parallel with the nearly horizontal bedding of the inclosing rock. They occur particularly along contacts between rocks of different kinds, as between dacite and limestone, between limestone and quartzite, or between limestone beds of different lithological character. Some of the ore bodies are directly connected with the Old Dominion fissure, the ore forming the hanging wall and extending irregularly for 20 or 30 feet out into the limestone. Such is the ore body still being worked in the principal open cut and shown in Pl. XXV, *A*. Others are apparently completely inclosed within the limestone, the latter, however, always showing more or less fissuring, such as may have given access to the ore-bearing solutions. As the ore lenses are followed toward the Old Dominion fault it is often found that they turn up at a steeper angle, and either wedge out in the limestone or continue on until they reach the fault. Whether the ore in such cases rises obliquely across the bedding, or the beds themselves are flexed upward close to the fault, could not be made out with certainty. The former, however, seemed more probable.

The lenticular wedge of quartzite lying between the Old Dominion and Interloper faults is much shattered, particularly above the third level, and has been extensively but irregularly mineralized, the ore not only filling the interstices but replacing to some extent the broken quartzite.

Of less importance as yet than the ores occurring in the hanging-wall limestone and quartzite are certain ore bodies found wholly within the diabase in the form of lodes. These lode ores are of two kinds—the oxidized ore, such as has hitherto been stoped from the North vein, and the sulphide ore occurring in the lower levels from the ninth down and not yet commercially extracted.

It thus appears that the ore of the Old Dominion mine has been deposited under rather varying conditions, which will be described in a little more detail and illustrated by a few specific examples before passing to considerations of genesis.

The occurrence of ore between limestone and dacite may be seen in a little stope from the first level in block xii. The ore is the usual brown, oxidized variety, and is of good quality. It lies upon limestone, which it penetrates irregularly as bunches and stringers, and is overlain by dacite, the contact dipping about 20° to the west-northwest. The ore appears to have been deposited and to have undergone oxidation before the eruption of the dacite, forming, with the eroded limestone, part of the predacitic surface. The dacite itself is unmineralized.

The occurrence of ore within the limestone is well illustrated in a small but representative stope connecting with the second level in block xv. The ore, which apparently contained a little more chrysocolla than usual, formed an irreg-

A. IN THE OPEN CUT OF THE OLD DOMINION MINE.

The even foot wall is diabase. The hanging wall is an oxidized mass of hematite and ore, extending irregularly into limestone on the left.

B. THE GREY MINE.

View is up Copper Gulch along the course of the Old Dominion fault. The Grey shaft is in the foreground, while just beyond it is the Grey incline. Behind the latter is the Cuprite shaft and Copper Hill. Black Peak lies against the sky to the left.

poorest of this pyritic ore contains about 3 per cent of copper, while much of it contains 5 per cent, and some more than this. It is, on the whole, a very low-grade ore. The copper is probably combined as chalcopyrite, but it is usually impossible to detect this mineral by the eye. Closely associated with the pyrite on the eleventh and twelfth levels, and sometimes enveloped in it, are bunches of massive copper glance or chalcocite. The occurrence of this mineral with the pyrite is of great interest, but unfortunately the character of the exposures now available is such that the relationship of the chalcocite to the pyrite could not be satisfactorily studied. Copper glance was first noted in the mine on the fifth level in block xxii, or about 350 feet below the surface, thus making its appearance before the pyrite.

The pyrite and chalcocite on the eleventh and twelfth levels form stringers sometimes as much as 5 feet in width. But the ore is not confined between definite walls. As regards the pyrite in particular, all gradations may be observed between solid ore, on the one hand, and altered diabase speckled with small crystals of the sulphide, on the other.

Grades of ore.—The ores of the Old Dominion mine have a wide range of tenor. That with less than 6 per cent of copper can rarely be profitably extracted, while ore containing 20 per cent is regarded as high grade. Most of the ore mined lies between these grades. It is obvious that the pyritic ore, when unaccompanied by chalcocite, is not at present workable.

Ground-water level.—The level of permanent water in the Old Dominion mine is rather difficult of definition. Oxidized ore prevails down to the tenth level, or to a depth of 600 or 700 feet. The change to sulphide ores occurs between the tenth and eleventh levels, and probably marks the original lowest level of standing water. At the present time great quantities of water find access to the mine through the upper levels southwest of the shaft. This influx, however, is probably almost entirely due to mining operations, whereby the water saturating the basal portion of the Gila conglomerate has been tapped and drained into the workings, whence it was formerly excluded by the dacite flow (see Pl. XXIII).

The influence of recent faulting upon the ore bodies.—Although fault slips later than the ore are of frequent occurrence throughout the mine, they have in most cases resulted merely in minor local complexities, such as have not seriously baffled the search for ore. In those portions of the workings lying northeast of the Alice tunnel and crosscut and southwest of the Interloper shaft different conditions, however, prevail.

Inspection of the plan of the mine shown in Pl. XXII discloses the fact that those workings obviously connected with extensive stoping all lie west of a north and south line drawn through the Alice crosscut about 150 feet from its mouth. East of such an imaginary line is a tract of apparently barren ground extending nearly to the Globe shaft. This change is well recognized as a practical factor in mining operations, and is usually accounted for by supposing that the ore is cut off by the so-called Alice fault. This explanation is supported by the following facts: (1) There is a strong fissure striking a little west of north and dipping west about 60° which has been followed for some distance in the Alice tunnel; (2) one of the largest ore bodies in the mine, that over the second level in blocks xxiii and xxiv, is said to have been cut off abruptly on the east by a strong fault slip dipping to the west; and (3) the nearly north and south drift on the second level extending from block xxiv-6 to block xxv-6 follows this fissure, which is without doubt the same as that already referred to in the Alice tunnel. The same fault has been supposed to appear in the crosscut from the second level in block xx-9; but this is doubtful. If the fault continues so far toward the south, it probably lies farther east.

Below the second level the Alice fault has not been recognized. The end of the third-level drift encounters a fault slip in block xxiv-6, which is about where the Alice fault should appear. But this fault dips to the east instead of to the west. This, taken in connection with what has already been seen in the Alice tunnel, as well as the presence of several fissures on the first level not previously referred to, suggests that the Alice fault is but one member of a complex zone of intersecting and nonpersistent faults of various strikes and dips, and confined to the hanging-wall side of the Old Dominion fault.

It is certain that these faults, whatever their origin, record recent or postmineral movement. It is fairly safe to accept the unanimous testimony of men familiar with the mine that the large body of ore above the second level was cut off abruptly by the Alice fault. Although it is possible that the Alice fault was initiated before the original ore deposition, and that the ore never extended beyond the fracture, yet this seems less likely than the alternative, that somewhere east of the Alice fault there is a continuation of the ore body. As the fault is probably normal, the continuation of the ore is likely to be found at a higher level than that already stoped. The occurrence of ore bodies east of the fault zone can not be demonstrated with the data at hand, but there is at least an inducement for further prospecting. How little exploration in this direction has actually been accomplished is evident from Pl. XXII. The plane of the Alice fault and its supposed continuation southward and downward seems to have been accepted on too slight investigation as an absolute barrier, beyond which it was useless to look for ore.

The development of that part of the mine lying southwest of the Interloper shaft (see Pls. XXII and XXIII) has been fraught with many perplexities. These have been due in part to real intricacy of the geological structure, and in part to erroneous interpretations of this structure. Among the latter may be cited the hitherto generally held view that the flow of dacite, or so-called "trachyte," is a dike, and that the granitic detritus overlying it and forming the base of the Gila conglomerate is really granite practically in place. Attempts have been made to cut through the supposed dike and to find some continuation of the Old Dominion fault beyond it. These have not only been futile, but by penetrating the dacite flow and tapping the porous water-bearing Gila formation they have allowed the underground water of the Globe Valley to flow into the mine and to seriously impede future development. When it is understood that the supposed trachyte dike is really a superficial lava flow resting upon an old surface of erosion and partly covered by the Pleistocene conglomerates that fill the Globe Valley, it becomes clear that attempts to penetrate it in search of ore are worse than useless. On the other hand, the fact that it is a flow and not a dike suggests that the lower levels of the mine when extended northwestward may pass entirely beneath the dacite, which will thus no longer cut off the ore-bearing ground in that direction. The general relation of the flow to the older rocks and to the overlying Gila formation may be seen from Pl. XXIII, in which an attempt is made to express, albeit somewhat diagrammatically, the most probable explanation of the observed facts in regard to the "west end" of the mine.

The idea that the dacite was a dike was supposed to receive confirmation from the fact that the second and fourth level drain tunnels both passed through a few feet of very much crushed soft "trachyte" into "granite" (Gila conglomerate). But this hypothesis overlooked a series of step faults, indicated in Pl. XXIII, which not only explain why the dacite was so abnormally thin where cut by these tunnels, but account also for its crushed condition. As may be seen from Pl. XXIII, the general effect of the faults, which are probably more numerous than there shown, is to give a deceptive impression that the dacite lies upon a much steeper slope than is really the case, and thus to afford fallacious support to the dike hypothesis.

The most important of these faults is exposed at several points on or near the surface, and is traced on the geological map (Pl. XV). It crosses the Mule tunnel (Pl. XXII) in block ix, near the junction of its two adit branches. Here it dips about 40° to the southwest, and drops the granitic Gila conglomerate against the dacite. The fault passes directly beneath the hoist of the Old

Dominion mine, and is well exposed in the cutting made for the engine house. It is cut by the Interloper shaft between the first and second levels, the shaft passing gradually from the conglomerate hanging wall into the dacite foot wall. Lastly, it is visible in the bluffs of Alice Gulch, southeast of the mine, where it drops higher beds of Gila conglomerate against the lowest granitic bed. The throw of the fault is probably about 75 feet. What appears to be the same fault was recognized crossing the various levels below the second, and is exposed at the southwest face of the eleventh level drift.

Other closely spaced faults lie southwest of this one, but are less clearly exposed, and apparently have smaller throws. Several of them are exposed in the conglomerate bluffs of Alice Gulch (Pl. XXI), and are met with in the underground workings.

One of the puzzling features encountered in developing the southwest end of the mine was the loss of the diabase foot wall, elsewhere so constant and characteristic. But a moment's consideration shows that this is a necessary and simple consequence of the displacement of a southeasterly-dipping fissure by a younger normal fault of southwesterly dip. A southwesterly drift along the Old Dominion fault will lose the diabase foot wall as it passes through one of these later faults, as, for example, at the southwest end of the eleventh level, and must be turned to the right, or northwest, to recover it.

While the foregoing facts throw some light upon the general structure of the southwestern portion of the mine, they do not account for all the complex details there found. In some part these are due to the locally irregular character of the diabase intrusion into the quartzite and limestone. But the disturbance and decomposition of the rocks is very great, and the developments, carried on without a clear conception of the dominant structure, lack the systematic character essential for the attainment of a complete grasp of structural details. The extensive oxidation of ore and country rock in the western end of the mine is in full accord with the hypothesis that the ore was present and partly oxidized at the old surface which the dacite subsequently buried.

In weighing the probabilities of finding further ore in the southwestern portion of the Old Dominion mine it should be borne in mind that the normal northwest-southeast step faulting not only offsets the Old Dominion fissure and associated ore bodies to the northwest, but has dropped them to a lower level. Hence oxidized ores may fairly be looked for southwest of this later fault zone at a depth which has brought the rest of the workings into sulphides. Rich oxidized ore occurs in limestone at the southwest end of the ninth level and may yet be found considerably lower, as the southwest drifts on the tenth level also show more or less oxidized ore associated with much limonite. All of the present workings on the eleventh and twelfth levels are below the zone of odixation, but it is not unlikely that they may encounter oxidized ore when pushed southwestward under the dacite flow. Inspection of Pl. XXIII shows that the eleventh level probably has from 400 to 700 feet farther to go before reaching the dacite, and if the zone of step faults is not more than 200 feet in width this level may pass entirely beneath the bottom of the lava flow, which will thus no longer cut off the ore to the southwest. Crosscuts to the northwest from the eleventh and twelfth levels, after they have been extended through the zone of step faults, should recover the offset portion of the Old Dominion fault, with a fair probability of finding oxidized ore beneath the dacite in the vicinity of this fault, and oxidized or sulphide ores in the underlying limestone and quartzite. Such exploration, however, is rendered difficult by the greatly disturbed character of the rocks within the zone of step faulting and the consequent great influx of water from the conglomerate-filled basin of the Globe Valley. Moreover, a large element of uncertainty is introduced by the possibility that the fault zone is a very wide one, and, by continuing to drop down, portions of the dacite flow may make it impracticable to extend even the twelfth level beneath the main body of the flow.

UNITED GLOBE MINES.

General statement.—This company was organized in 1892, and various properties, among which the most important at that time were the Buffalo and Hoosier mines, were thereby consolidated. At present the company owns between thirty and forty claims lying north and east of the Old Dominion mine. The more important of their various workings will be described under the following headings: "Grey mine," embracing the Hoosier, Grey, Cuprite, Transit, Nevada, Amador, Gladiator, and Centralia claims; "Buffalo mine," including the Buffalo, Mark Twain, and Lizzie claims; "Josh Billings mine," "Big Johnnie mine," "Buckeye mine," and "Stonewall mine."

Grey mine.—This comprises a series of workings which form practically a northeasterly continuation of those belonging to the Old Dominion mine, and extend for an additional length of about 3,500 feet along the Old Dominion fault (see Pl. XXVI). The principal adit is the new Grey shaft (Pl. XXV, *B*) in Copper Gulch, about 4,500 feet northeast of the Interloper shaft; but much work was formerly done through the Hoosier shaft, about 1,400 feet southwest of the Grey. Other adits formerly used are the Transit shaft, about 300 feet west of the Hoosier; the Centralia tunnel, connecting with the second level from Copper Gulch; the Grey incline, a little over 300 feet northeast of the Grey shaft, and the Cuprite shaft, about 400 feet northeast of the Grey incline.

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Prior to 1892 considerable oxidized ore had been mined from the open cuts and superficial workings in the limestone, which are noticeable just below the road and about halfway between the Hoosier and Grey shafts. This led to the sinking of the vertical Hoosier shaft through the limestone here forming the hanging wall of the Old Dominion fault. The shaft cut the fissure between the eighth and ninth levels, at an approximate depth of 600 feet. Apparently no very large bodies of ore were encountered in the neighborhood of the Hoosier shaft, and the levels below the sixth have been allowed to fill with water.

The Grey shaft is sunk in the foot wall chiefly through diabase, but cutting also some masses of quartzite. In January, 1902, it had reached a depth of about 700 feet, the lower 400 feet (below the sixth level) being mainly in diabase. The principal levels are the second and sixth, 86 and 340 feet, respectively, below the collar of the Grey shaft. Both of these levels connect with the Hoosier shaft through long drifts run on the Old Dominion fissure, the dip of which varies from 50° to 70°, but is usually steeper than in the Old Dominion mine.

Northeast of the Grey shaft the same fissure has been followed to the Cuprite shaft, but becomes less well defined beyond that point. As far as it has been followed it shows no perceptible offsetting by later faults.

The country rock of the Grey mine is similar to that of the Old Dominion, but is less regular in its distribution. Masses of limestone and quartzite inclosed in the diabase are exceedingly common, and abrupt changes in the lithological character of foot wall or hanging wall are therefore of frequent occurrence, particularly in the lower levels.

In part this irregularity is due to faulting, but the character and structural influence of this faulting is masked by the extensive inclusion of masses of strata within the diabase at the time of the latter's eruption. The effect of the intrusion was to produce a structure so erratic in its heterogeneity that it is generally impracticable to determine to how great an extent later faulting has increased this complexity. It is impossible with the present facilities for observation to satisfactorily reconstruct the intricate fabric that existed prior to the dislocations that followed the diabase intrusion.

From the crosscut to the Nevada vein (Pl. XXVI) southwestward to the Transit shaft the main drift of the second level follows in general a regular foot wall of diabase. The hanging wall is limestone, but more or less crushed quartzite occurs along the fissure, probably dragged in by faulting.

North of the Transit shaft some work has been done on the so-called Foot-wall vein, which is identical with the North vein in the Old Dominion ground. As this vein dips to the northwest, while the Old Dominion fault dips southeast, the two come together north of the Transit shaft, just above the second level, and a body of ore, now stoped out, occurred at their junction.

The Nevada vein, northwest of the Grey shaft, perhaps a continuation of the Foot-wall vein, is reached by a northerly crosscut from the second level drift (see Pl. XXVI). This crosscut follows a fault with a westerly dip of about 80°, and having diabase on the hanging wall and quartzite overlain by limestone on the foot wall. This is probably the fault shown 300 feet west of the Grey shaft on the special geological map (Pl. XV). The Nevada vein dips northwest at an angle of about 50°, and has a diabase hanging wall and a quartzite foot wall. Thus within the diabase, which is the preponderant rock on the foot-wall side of the Old Dominion fault, is a mass of quartzite and limestone known to be overlain and underlain by diabase and limited in its horizontal extent on at least three sides by faults later than the diabase intrusion. But, although these faults now bound the mass in part, they can not wholly account for its position within the diabase, and this block of quartzite and limestone illustrates on a considerable scale a feature occurring again and again in the deeper workings, particularly those northeast of the Grey shaft, and rendering it impossible to predict what rock the next few feet of drifting may reveal.

Most of the faults observed have dips greater than 45° and probably normal throws. A rather flat fault was observed, however, in a northwest crosscut on the sixth level about 250 feet northeast of the Grey incline. In this case the fault plane dips to the northeast at an angle of about 15°. The hanging wall is diabase and the foot wall is shattered quartzite. The direction of relative motion, however, is unknown.

The ore formerly extracted from the superficial workings between the Grey and Hoosier shafts occurred in irregular oxidized masses in the hanging-wall limestone, closely resembling those described in the Old Dominion mine. According to Mr. N. S. Berray, a distinction was recognized between the limestones in the Hoosier workings, the large replacement bodies of ore being confined to an upper division of gray, rather thin-bedded limestone, while in a lower massive buff limestone the ore was found only in veins or "verticals." There was no opportunity to verify this statement at the time of visit, but it is certain that no such distinction holds in the neighboring Old Dominion mine.

The greater part of the workings connected with the Grey shaft have been run for prospecting purposes, and the mine is not as yet an extensive producer. Practically all of the ore of late has come from the vicinity of the Cuprite shaft.

One considerable body occurs in shattered quartzite above the fourth level and just northeast of the Cuprite shaft. It consists chiefly of carbonates and oxide, and resembles the ore occurring in the quartzite of the Old Dominion mine. Much of the shattered quartzite in the vicinity of the main Old Dominion fault is stained green with carbonate of copper, but the mineralization is not always sufficient to make ore.

mineralized zone to within about 540 feet of the face of the main drift. diabase appears and continues for about 20 feet along the drift, being suc on the northeast by hard white quartzite, in which no continuation of th eralized zone has been found. The diabase is apparently brought in by faults, which have offset the main fissure zone, followed by the tunnel f greater part of its length.

The ore of the Buffalo mine occurred between the second level and the s in the shattered wedge of quartzite and limestone lying between the tw faults. That nearest the surface and first mined occurred as oxidized repla masses in the limestone, associated with much limonite, as in the Old Do mine. But the shattered quartzite underlying the limestone in the fault as well as the quartzite of the fissure walls, was also mineralized, an extensively stoped after the ore in limestone had been exhausted.

The ore, consisting of malachite and cuprite, with occasional residual or kernels of chalcocite, occurs chiefly as a filling of the interstices and fractures in the shattered quartzite. Microscopical examination of thin s of the ore shows that molecular replacement of the quartzite has also place, but this process appears to have been subordinate to the filli mechanically formed cavities. The quartzite ore is destitute of well- walls, but grades irregularly into quartzite containing too little copper t for working.

The most interesting features of the ore occurrence are the prese chalcocite or copper glance so near to the surface, and the apparent total a of ore in the diabase beneath the quartzite and limestone.

Josh Billings mine.—The Josh Billings vein outcrops in quartzite alo crest of Buffalo Ridge, with a general strike of north 40° east, and a dip of 75° to the southeast. It fills a normal fault fissure, the throw of which is 60 feet.

Some prospecting has been done on that portion of the vein in the qua but without success, the vein apparently splitting up into small stringers rock and carrying but little ore. All of the present workings are entirely diabase beneath the quartzite, and comprise three tunnels that exploit th through a vertical distance of about 400 feet. The lowest, or Maggie, crosscuts north to the Maggie, a vein similar in character and parallel Josh Billings, but lying about 300 feet farther northwest. After d northeast on this vein for about 650 feet a crosscut was run back south Josh Billings.

The Josh Billings vein is a fairly regular fissure in the diabase, ca bunches of high-grade (20 per cent) ore, which is oxidized below the p

A. THE BUFFALO MINE, FROM THE RIDGE SOUTH OF ALICE GULCH.

B. THE CONTINENTAL MINE, FROM THE SOUTH.

The black lines indicate approximately the outcrops of some of the principal faults. The mine buildings and the entrance to the main tunnel are behind the diabase spur skirted by the road in the middle ground of the left side of the view. The ore occurs within the granitic mass which outcrops prominently on the sky line. The Ninety Six shaft is in the little ravine where the two faults bounding the smaller mass of granite meet at an acute angle.

depth of working. There is usually a clay gouge on one side of the ore, showing recent movement. Regular walls are lacking, however, and the ore extends for varying distances into the diabase. The Josh Billings and Maggie veins are similar to the North vein in the Old Dominion mine, and with increasing depth will change to sulphide ore and then resemble the lodes met with in the eleventh and twelfth levels of that mine.

Ore was being shipped from the Josh Billings vein at the time of visit, but although a single body of very good ore has been stoped from the neighboring Maggie vein, work on this lode has been for the present abandoned.

Big Johnnie mine.—This property is on a mineralized fault breccia in Big Johnnie Gulch, on the western slope of Black Peak. The fault strikes about north 40° east, and dips northwest at an angle of 75° or 80°. It is exploited by tunnels and open cuts, and has produced some very good ore. Although worked by lessees in the summer of 1901, the mine was idle at the time of visit.

As in the Josh Billings mine, the fissure cuts quartzite underlain by diabase, but, unlike that vein, the ore here occurs in the quartzite, while a lower tunnel run in the diabase failed to find anything of value. The conditions are thus similar to those met with in the Buffalo mine. The quartzites near the fissure dip southeast at about 40°, but flatten toward the southeast to a general dip of 15°, with a strike of north 80° east.

The average width of the fault breccia is something less than 2 feet. It consists of fragments of quartzite cemented and partly replaced by cuprite, malachite, chrysocolla, and hematite. Apparently most of the ore has been taken from open cuts along the summit of the lode, which in places splits into two or more closely parallel veins.

Buckeye mine.—This lies on the southern slope of Copper Gulch, near its head, on a vein in quartzite (Pl. XV). The strike of the vein at the mine is about north 45° east, but, as may be seen from Pl. XV, it has a curved course and soon turns more easterly. The dip is from 50° to 60° to the northwest. The lode is exploited by a lower tunnel about 300 feet in length, and numerous shorter tunnels and open cuts extending up to the top of the hill and covering a vertical distance of about 200 feet. Most of the ore has come from the open cuts and superficial upper tunnels.

It occurs irregularly in the brecciated quartzite of a fissure zone as bunches that rarely occupy the full width of the zone. The greater part of the ore, consisting of cuprite, malachite, and chrysocolla, occurs as a filling of the interstices and small fissures in the shattered quartzite, but there has also been some replacement of the quartzite fragments themselves.

The mine has been worked intermittently for several years, chiefly by lessees, and the amount of ore shipped has not been large. Some of it, however, is of high grade. That being shipped in 1901 was said to contain from 20 to 35 per cent of copper, and to carry occasionally as much as 8 ounces of silver and a tenth of an ounce of gold.

Stonewall mine.—This is situated about 1,500 feet south of the Buckeye, and resembles the latter in being wholly in quartzite. The principal fissure strikes north 68° east, and dips northwest at an angle of about 75°. Just north of it lies a second fault, which joins the first in the ravine west of the mine. A third fissure, the Arizona, with a nearly east-west course, falls into this second lode from the west. The ore apparently occurs chiefly in the disturbed quartzite between the first and second fissures. It is mineralogically similar to that of the Buckeye, but apparently contains much more hematite. The mine has been worked intermittently on a small scale for several years, principally by lessees.

OTHER MINES IN THE GLOBE HILLS.

Copper Hill mine.—This embraces most of the workings on Copper Hill. just northeast of the Grey mine. The surface rock of the hill is quartzite, dipping generally to the southwest at an angle of 20° or 25°. On the northeast these quartzites are dropped against the diabase of the head of Copper Gulch by the strong, curved Budget fault (see Pl. XV). On the west they are bounded by another nearly north-south fault, which dips to the west, and has dropped limestone, quartzite, and diabase on that side. Between these two faults the quartzite of Copper Hill is traversed by numerous closely spaced, approximately parallel fissures, striking about north 50° east. These fissures, which appear to have been formed with very insignificant displacement, are filled with quartzitic breccias from 2 to 4 feet in width, most of which show more or less mineralization, while the intervening quartzite is frequently fissured and stained with carbonate of copper. Most of the breccias have been explored by open cuts and some malachite ore taken out, but the great bulk of the ore is apparently very low in grade. In 1901 a shaft was being sunk on one of these fissures, in Copper Gulch, at the northwest foot of the hill. About 15 feet below the collar the shaft passed from quartzite into diabase, which apparently underlies the quartzite of Copper Hill, and was still in the same rock at the time of visit.

Original Old Dominion mine.—This is situated on the east side of Pinal Creek, about 4 miles north-northeast of Globe, on a clean-cut fissure vein in quartzite. It was one of the earliest mines to be worked in the region, and was noted in the early eighties for beautiful specimens of free gold with copper carbonates and calcite. It was developed through several tunnels, and produced considerable ore, but has been idle for several years, save for the occasional operations of lessees.

The vein strikes north 30° east, and dips southeast at 75°. It cuts obliquely across the beds of quartzite, which strike about north 80° east, and dip at 45° to the south. The throw of the fault is unknown.

The vein, where seen, is less than a foot in width, but fairly regular, and shows no recent movement.

The ore is oxidized to an unknown depth. It consists of an ocherous dark-red mixture of cuprite and iron oxide finely streaked with chrysocolla and malachite, and sometimes showing native gold in the form of short wires and thin leaves. The gold is usually embedded in the red oxides.

Mallory or I X L mine.—This is situated on the northwest side of Big Johnnie Gulch, the workings comprising several tunnels and a new shaft. There are two principal fissures, one striking about north 35° east, and apparently passing directly through the shaft, and the other striking about north 10° east, and meeting the former about 300 feet southwest of the shaft (see Pl. XV). Between the two faults lies a mass of reddish grit and quartzite, apparently of no great thickness, and evidently overlying diabase. These grits are traversed by several small fractures carrying some oxidized copper ore, and they exhibit considerable diffused mineralization and staining by copper carbonates. The shaft has penetrated below the quartzite, and gone down for some distance in diabase without finding any pay ore. The conditions appear to be similar to those already described in the Buffalo, Big Johnnie, and Copper Hill mines.

MINES NORTHWEST OF GLOBE.

Black Warrior.—This company controls numerous claims in the lower part of Webster Gulch, none of which have yet been steadily productive. The principal development has been on the Montgomery, a prospect situated nearly a mile southwest of the settlement of Black Warrior and connected by a tramway with the smelter and leaching works.

The development consists of three tunnels, of which the middle and lowest are the more important. The country rock includes dacite, dacite tuff, and Pinal schist, and their relations are shown in fig. 8 (p. 156), which is a diagrammatic cross section through the mine. As there indicated, the workings are related to a fault, of probably less than 50 feet throw, striking nearly east and west and dipping steeply to the south at varying angles. This fault has dropped dacitic tuff and overlying massive dacite on the south, against schist on the north.

The ore, which is wholly oxidized, occurs in the dacite tuff on the hanging-wall side of the fault. The middle tunnel penetrates this mineralized tuff for a devious westerly course of some 300 feet. The tuff is approximately 50 feet in thickness, and rests upon an uneven erosion surface of much-shattered schists. It is overlain by massive vitrophyric dacite. When unmineralized the tuff is a soft, brownish or grayish material, glistening with flakes of biotite and containing small fragments of schist and quartz. As seen in the middle tunnel, the tuff, as well as the underlying schist, has undergone great disturbance and is traversed by countless small irregular faults in part later than the ore.

The latter occurs as irregular streaks of soft chrysocolla, often nearly black, from the presence of manganese oxide. The chrysocolla seldom forms solid masses, but permeates the soft, altered tuff, forming an ore of very low grade, probably rarely carrying over 5 per cent of copper. There are all gradations from this ore to slightly mineralized tuff merely tinged with the green tint, which shows the presence of a little chrysocolla or malachite. The ore streaks usually lie nearly horizontal, or dip gently to the northwest, following the rather indistinct bedding planes of the tuff.

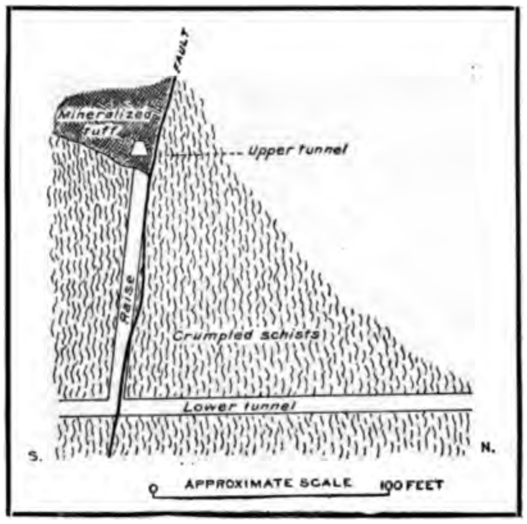

Fig. 8.—Diagrammatic section through the underground workings of the Montgomery claim of the Black Warrior group.

The lower tunnel is wholly in schist, showing no ore and scarcely a trace of mineralization, even along the main fault. Raises from this tunnel reach the mineralized tuff above, and connect with the middle tunnel.

No work was in progress on the Black Warrior claims at the time of visit, although the company was erecting an extensive acid plant for leaching purposes.

Black Copper mine.—This is situated in Webster Gulch, about 2 miles southwest of Black Warrior. The principal workings comprise a vertical shaft about 250 feet in depth, with three levels, of which the second, about 80 feet below the surface, is the most important. There are also some minor superficial workings about 350 feet a little south of west from the main shaft.

The country rock includes Pinal schist and dacite, the ore occurring between the two, as shown in fig. 9. This ore is of the same general mineralogical character as that found in the Montgomery and Geneva claims, being a fragile, brittle chrysocolla, often so dark in color as to closely resemble bituminous coal. It is sometimes as much as 12 feet in thickness, resting upon a foot wall of much broken and disturbed schist and overlain by dacite. The dip of the ore body is easterly at an average angle of 35°.

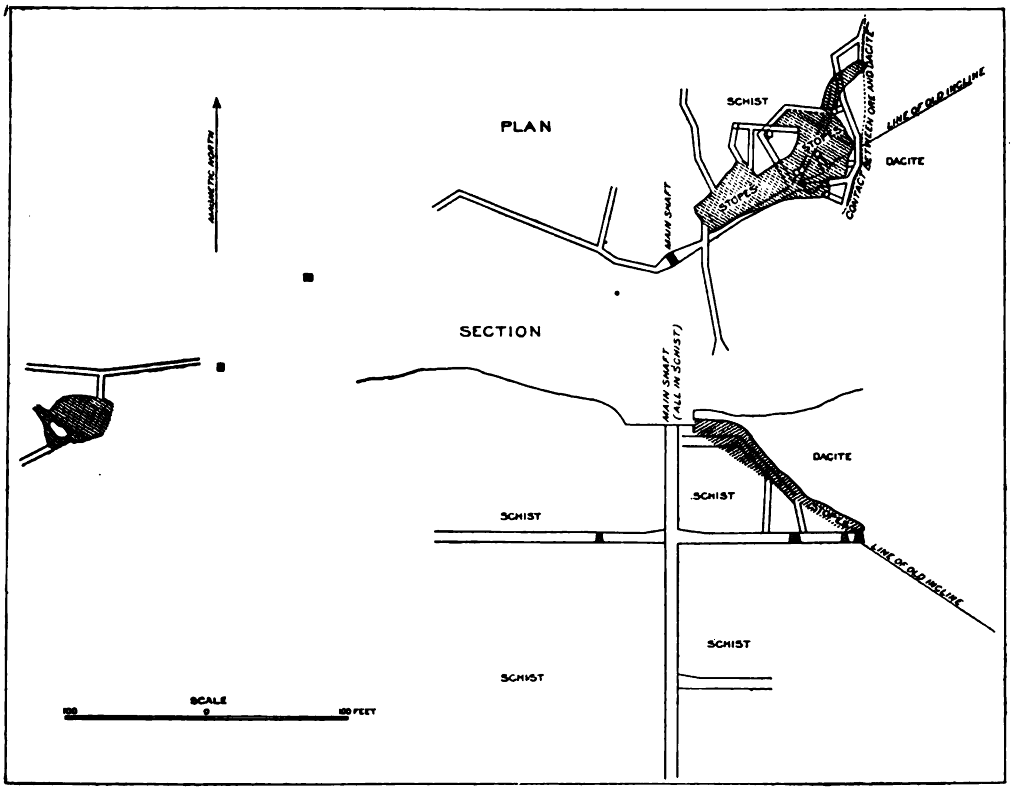

FIG. 9.—Plan and section of the Black Copper mine.

According to Dr. Irving, who visited the mine and from whose notes this description is compiled, the contact between the schist and dacite is primarily a normal fault of a rather low angle of dip. The evidence for this, however, is not entirely convincing. The ore is clearly a replacement of dacitic material, as shown by the presence in much of it of little scales of biotite, which is usually the last constituent of the dacite tuff to disappear in the process of ore replacement. This fact, and the similarity of the ore to that of the Geneva and Montgomery mines, taken in connection with the low angle of dip, is suggestive of its occurrence along the contact between an old eroded surface of schist and overlying dacite tuff or dacite. However, it probably is impracticable to prove from facts observable in the present workings whether or not there was faulting along the contact prior to mineralization.

Since the ore deposition considerable faulting has evidently taken place, as shown by slip planes, polished slickensides, and brecciation of the ore.

Below the second level the workings are all in schist, showing the astonishingly minute shattering characteristic of this rock in the lower part of Webster Gulch, and slightly stained with salts of copper.

The ore of the Black Copper mine carries from 10 to 22 per cent of copper, the green chrysocolla being higher grade than the black ore.

Geneva mine.—This is a small property lying about half a mile southwest of Black Warrior and belonging to the United Globe Company. In the occurrence of its ore it shows some resemblance to the Montgomery claim already described. The country rock is dacite tuff, resting upon an uneven, eroded surface of Pinal schist. The ore is chrysocolla, frequently occurring in nearly pure masses, and of sufficiently high grade to ship, the best of it containing about 20 per cent of copper. Its appearance is very striking, as coal-black, green, and turquoise-blue varieties of the copper silicate occur mingled together in a brittle mass having a highly resinous luster. The black variety, which, as chemical tests by Dr. Hillebrand show, owes its dark color to the presence of one of the higher oxides of manganese, shows a tendency to occur in irregular blotches or kernels which grade outwardly through successive concentric shells into green, and finally into pale-blue forms of the mineral, the last sometimes lining small vugs in botryoidal incrustations. The ore is plainly a replacement of the tuff, and various degrees of alteration are exhibited, from tuff slightly flecked with chrysocolla to ore such as that described, in which an occasional flake of biotite is the only vestige of its former tuffaceous nature. The cause of the striking mottled structure is not wholly understood, although it is apparently due to selective and successive action of the mineralizing solutions upon the constituent particles of the tuff.

The dacite tuff in which the ore occurs is 40 or 50 feet in thickness, and rather obscurely bedded or laminated. Particles of schist are abundant, and they, as well as the eruptive material of the tuff, have been locally replaced by ore.

The ore occurs as a nearly horizontal blanket-like body 4 feet in maximum thickness, 15 feet wide, and of unknown length, lying near the base of the tuff. This ribbon of ore trends nearly east and west and dips north at a low angle. In some places it rests directly upon the schists, in others it is separated from the latter by a layer of altered tuff. It seldom possesses definite boundaries, but shades off gradually into low-grade ore, and this into kaolinized tuff faintly tinged green by a trace of copper.

The tuff and ore is cut off on the east by a normal fault that has dropped them against the Pinal schists, as in the Montgomery claim. The whole deposit, moreover, is disturbed by small normal faults, most of them showing recent movement.

The ore is unsystematically mined by lessees through shallow shafts sunk through the tuff to the ore-bearing horizon, and connecting with drifts and stopes in the ore.

Continental mine.—This mine (Pl. XXVII, *B*) is situated just over the divide from the head of Webster Gulch, within a rather intricately faulted complex of diabase, Schultze granite, Globe limestone, and the Whitetail formation. The mine, although located twenty years ago, first began to attract attention about the year 1896, considerable development work then being done and the presence of rich ore ascertained. In 1899 it was purchased by the Old Dominion Company. No ore has yet been shipped.

The workings consist of three tunnel levels with several hundred feet of drifts and crosscuts, two levels, the fourth and fifth, below the third level tunnel, which is the main adit, and some small shafts. The total depth reached is about 350 feet.

As may be seen from the geological map (Pl. I), several structurally important faults converge at the Continental mine, and, as is usually the case, the rocks in the vicinity of the intersection are not only disturbed by the main faults, but by many minor dislocations as well. The general plan of these faults is diagrammatically shown in fig. 10.

The faults are apparently all normal, the diabase having been dropped against the granite. They probably antedate the period of mineralization in the main, but all show evidence of some recent slipping.

The main adit tunnel runs north for about 215 feet in diabase, and then passes through a fault plane into a triangular block of granite-porphyry, within which are situated the main workings and the ore bodies. So far as known, the ore is confined to this small mass of porphyry and a smaller block lying between it and the Ninety-six shaft (see fig. 10 and Pl. XXVII, *B*), while the faults bounding these blocks, and the surrounding diabase, limestone, and granite-porphyry, contain, so far as known, no mineralization of economic importance. The ore occurs in connection with minor fissures within these two bodies of porphyry, particularly within the larger one, and not in the stronger faults that inclose the latter.

The main vein, as shown in fig. 10, has a curved course ranging from northeast at its eastern end to nearly northwest at its western end. Below a depth of about 100 feet from the surface the ore occurs as a bunchy vein of quartz, pyrite, and a little chalcopyrite, passing into mineralized porphyry without sharply defined walls, and showing considerable recent movement along the fissure. This sulphide ore is low grade, carrying from 2 or 3 per cent up to an occasional tenor of 20 per cent of copper.

For a distance of about 100 feet down from the surface the vein is oxidized and contains some small bodies of rich ore, consisting of cuprite, malachite, and azurite, with native silver. The latter occurs chiefly in calcite, tinged green and blue by the carbonates of copper, which often form the gangue of the cuprite.

It is not known whether any chalcocite or other cupriferous sulphide occurs between the oxidized zone and the low-grade pyritic ore below. None was seen at the time of visit.

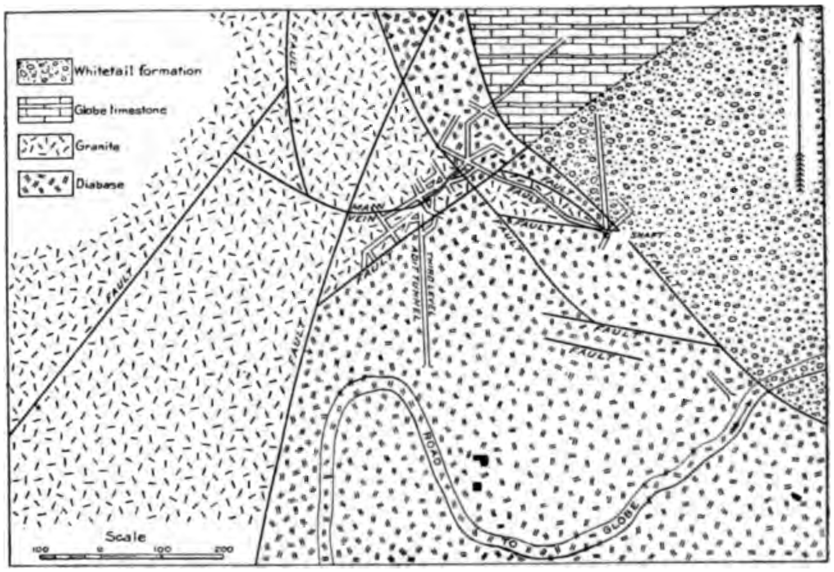

FIG. 10.—Diagram showing plan of faulting at the Continental mine.

The occurrence of goslarite, or hydrous sulphate of zinc, as a fluffy efflorescence of acicular crystals coating some of the drifts, was noted as a rather peculiar feature, as no zinc-bearing minerals were seen in the ore.

Keystone mine.—This is situated about a mile and a half north of Bloody Tanks, in granitic porphyry forming part of the Bloody Tanks area of the Schultze granite. The ore occurs as a fairly regular and persistent vein of chrysocolla striking north 40° west, and dipping northeast at an angle varying from 40° to 50°. The maximum width of the ore is about 18 inches.

The developments comprise two tunnels on the vein, about 50 feet apart, the upper or main tunnel being about 350 feet in length. Most of the ore has come from stopes above the main tunnel. The richest contains about 25 per cent of copper, and the total output of the mine, which has been operated for only two or three years, is given as about $25,000.

The ore is bluish-green, brittle chrysocolla, adhering finely to the porphyry walls of the fissure and frequently inclosing fragments of the country rock. For the most part it plainly fills mechanically formed spaces, but there has been apparently some minor replacement of the fractured porphyry by ore. Occasionally a little quartz and malachite occur in the vein, the latter as streaks in the chrysocolla.

At the mouth of the lower tunnel a small stringer was seen carrying pyrite, but no trace of the presence of original sulphides has yet been found in the Keystone vein.

The granite-porphyry in the vicinity of the Keystone mine is much fractured and filled with small stringers of chrysocolla, rarely very persistent, but sometimes large enough to furnish a little marketable ore. Such is a vein lying a few hundred feet west of the Keystone, and approximately parallel to the latter in strike and dip, which has been superficially stoped from the surface.

Liveoak mine.—This mine, in Liveoak Gulch, about a third of a mile south of the Keystone, shows similar ore. The main tunnel enters a bold cliff of porphyry, here vividly stained with copper and affording some ore close to the surface. It is reported that some of the ore in the Liveoak mine occurred alongside schist, probably an included mass in the Schultze granite. No ore was being shipped at the time of visit, and the underground workings were not examined.

MINES IN SCHIST ON THE WESTERN SLOPE OF THE PINAL RANGE.

General character.—These are small mines or prospects in which the ore occurs, principally in the form of sulphides, in fissure veins traversing Pinal schist. The more important properties are the Bobtail, Cole & Goodwin, and Summit mines, all showing ore bodies of considerable promise.

Bobtail mine.—This is situated on the north side of Mineral Creek, not far from its head, and was at the time of visit in a rather inaccessible position. Improvements in transportation and treatment of the ore were, however, then in contemplation, and have probably since been carried out.

The Bobtail vein strikes north 35° east, and dips 62° to the northwest, thus cutting obliquely across the schistosity of the Pinal schists (Pl. I). An inclined shaft has been sunk on the vein to a depth of 150 feet, and was being carried down to 200 feet at the time of visit. Connecting with this shaft are short drifts 50 and 100 feet below the surface.

The vein is a strong one up to 6 feet in width, the ore minerals occurring as a cement holding together fragments of a schist fault breccia. These fragments are of somewhat bleached and altered sericite-schist of the same character as that forming the walls of the lode and containing a little finely disseminated pyrite. Soft gouge and slickensides show that there has been some slipping along the fissure since the ore was deposited.

The ore, practically from the surface down, consists of chalcopyrite, sphalerite, galena, and pyrite, named in order of abundance. The sulphides have crystallized, without any recognizable sequence, in the interstices between the schist fragments. They are sometimes associated with a quartz gangue, but this mineral is not always present in noticeable quantity. The best of the ore is said to contain 18 per cent of copper, 30 ounces of silver, and an ounce of gold per ton, but the average is undoubtedly very much lower than this.

The tungstate of manganese and iron, hübnerite, is frequently encountered as small prismatic crystals embedded in the quartz of the more siliceous parts of the vein. It is apparently of the same general age as the associated sulphides.

Cole & Goodwin mine.—This is situated on the north side of Lyons Fork of Mineral Creek, about 2½ miles southwest of the Hog ranch.

The vein strikes north 48° east and dips northwest at an angle of 41°. Like that of the Bobtail, it is a mineralized fault breccia in schist, varying from 2 to 4 feet in width. It is opened by an inclined shaft about 200 feet in depth and some short drifts.

The ore, almost from the surface down, consists of chalcopyrite and pyrite, with some calcite and occasionally a little quartz. It occurs in bunches, and in part as a replacement of the sericite-schist of the breccia fragments and vein walls. The best ore is said to occur where the schist shows most alteration and mineralization. The richest ore contains about 14 per cent of copper and occasionally as much as $3 per ton in gold and silver.

A road to the mine was begun early in the year 1902, with the intention of mining and shipping this ore.

Summit mine.—This little mine lies near the head of the Dry Wash of Mineral Creek, on a vein striking with the schistosity of the Pinal schists north 30° east, and dipping northwest, also conformably with the latter, at an angle of 45°. The developments consist of a tunnel on the vein about 350 feet long and some small stopes.

The ore fills a simple fissure up to 2 feet wide, sometimes accompanied by smaller, nearly parallel, veins or "streaks" in the foot or hanging wall. No replacement of schist was noted. Much of the ore occurs as a soft, somewhat shattered black mass, and it is only when the dark fragments are freshly fractured that it is seen to consist chiefly of massive chalcopyrite, the dark material being merely an external film. A chemical examination of this coating by Dr. Stokes confirmed the conclusion reached in the field that it is a sulphide of copper, probably chalcocite. Occasionally the chalcopyrite is honeycombed with an earthy mixture of this amorphous chalcocite and minutely crystalline specular hematite.

The ore contains from 10 to 25 per cent of copper, and small shipments were being made in 1901.

There are several other veins in the schists in the vicinity of the Summit mine, some of which were being prospected in 1901, but no bodies of workable ore had been uncovered at the time of visit.

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